PB-215 517

PROCEEDINGS: NATIONAL SYMPOSIUM ON FOOD PROCESSING WASTES (2ND), DENVER, COLORADO, 23-26 MARCH 1971

Pacific Northwest Water Laboratory

Prepared for:

Environmental Protection Agency

March 1971

DISTRIBUTED BY:

NTIS

National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151

PB 215 517

CLEAN WATER

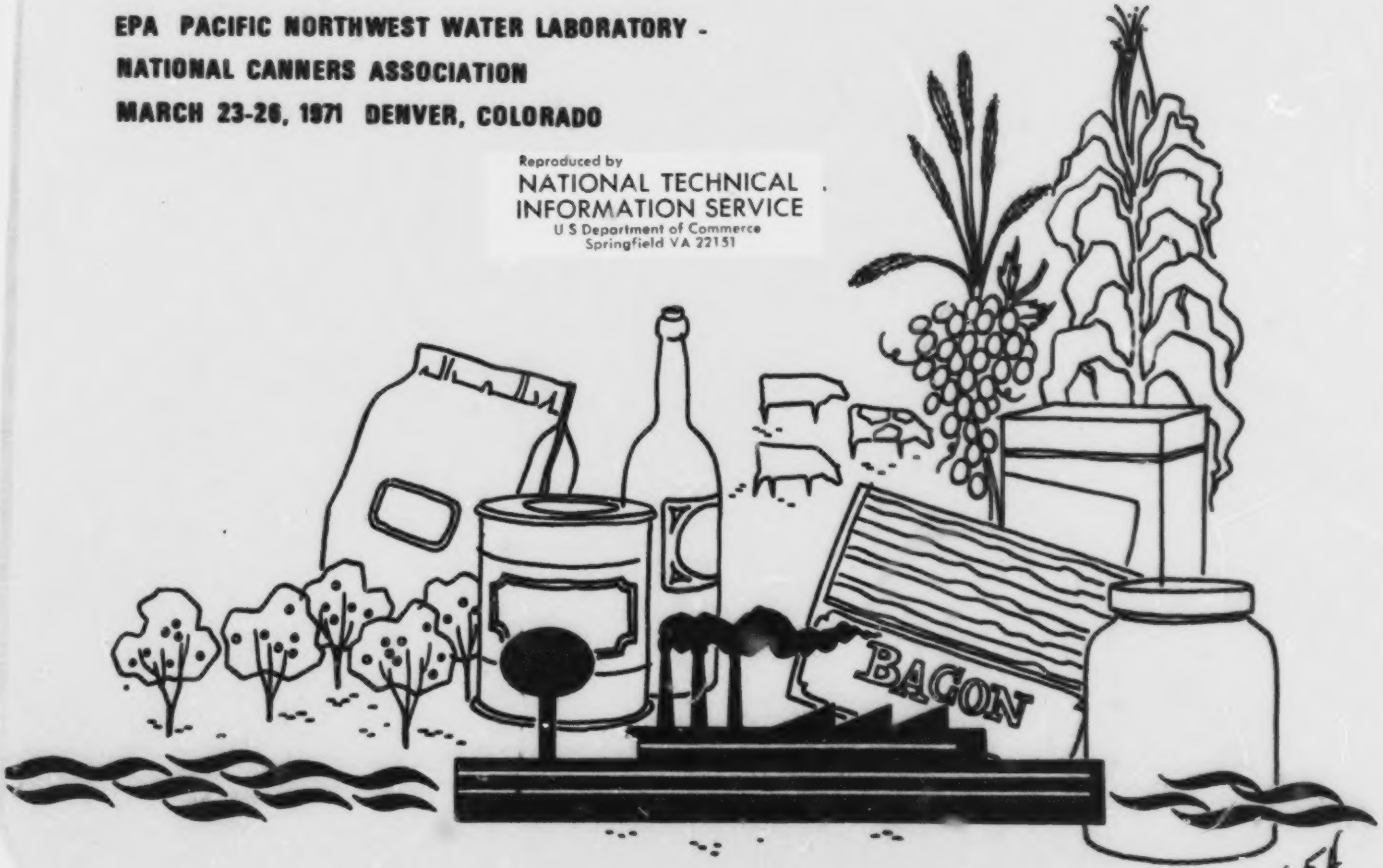
WATER POLLUTION CONTROL RESEARCH SERIES ● 12060---03/71

PROCEEDINGS
SECOND NATIONAL SYMPOSIUM ON FOOD PROCESSING WASTES

CO-SPONSORED BY:

EPA PACIFIC NORTHWEST WATER LABORATORY -
NATIONAL CANNERS ASSOCIATION
MARCH 23-26, 1971 DENVER, COLORADO

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
U S Department of Commerce
Springfield VA 22151



654

VIRONMENTAL PROTECTION AGENCY ● RESEARCH AND MONITORING

WATER POLLUTION CONTROL RESEARCH SERIES

The Water Pollution Control Research Series describes the results and progress in the control and abatement of pollution of our Nation's waters. They provide a central source of information on the research, development, and demonstration activities of the Environmental Protection Agency, through inhouse research and grants and contracts with Federal, State, and local agencies, research institutions, and industrial organizations.

Inquiries pertaining to the Water Pollution Control Research Reports should be directed to the Head, Project Reports System, Office of Research and Monitoring, Environmental Protection Agency, Room 801, Washington, DC 20242.

PROCEEDINGS

SECOND NATIONAL SYMPOSIUM ON FOOD PROCESSING WASTES

Co-sponsored by:

Pacific Northwest Water Laboratory, EPA

and

National Canners Association

March 23-26, 1971
Denver, Colorado

I

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price $4.50
Stock Number 5501-0167

EPA Review Notice

This report has been reviewed by the Water Quality Office of the Environmental Protection Agency and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

This Second National Symposium on Food Processing Wastes was co-sponsored by the Pacific Northwest Water Laboratory of the U. S. Environmental Protection Agency, and the National Canners Association. The meeting was held this year in Denver, Colorado, in keeping with the plan to rotate the meeting among different geographical locations.

The meeting was expanded to four days in order to provide time for discussion of air pollution and solid waste programs as well as the reports on new waste treatment research. It is hoped that these meetings have set a precedent for a continuing forum for researchers and industry officials to discuss questions and answers on environmental protection.

CONTENTS

SYMPOSIUM OBJECTIVES 1

James R. Boydston

ENVIRONMENTAL QUALITY CONCERNS OF THE FOOD PROCESSING INDUSTRY 3

Alvin H. Randall

EPA'S INDUSTRIAL POLLUTION CONTROL PROGRAM 13

Dr. Stanley M. Greenfield

THE CLEAN AIR AMENDMENTS OF 1970 and AIR POLLUTION ASPECTS OF THE FOOD AND AGRICULTURAL PROCESSING INDUSTRY 21

Dr. S. David Shearer

ACTIVITIES IN MANAGING SOLID WASTES 41

Jack DeMarco

POLLUTION ABATEMENT AND BY-PRODUCT RECOVERY IN THE SHELLFISH INDUSTRY 51

Edwin Lee Johnson and Dr. Quintin P. Peniston

SALT RECLAMATION FROM FOOD PROCESSING BRINES 75

E. Lowe and E. L. Durkee

REDUCTION OF SALT CONTENT OF FOOD PROCESSING LIQUID WASTE EFFLUENT 85

Dr. Jack W. Ralls, Walter A. Mercer and Nabil L. Yacoub

PRODUCTION AND DISPOSAL PRACTICES FOR LIQUID WASTES FROM CANNERY AND FREEZING FRUITS AND VEGETABLES 109

Walter W. Rose, Walter A. Mercer, Allen Katsuyama, Richard W. Sternberg, Glen V. Brauner, Norman A. Olson, and Dr. Kenneth G. Weckel

Preceding page blank

PROGRESS REPORT: STUDY OF DRY CAUSTIC VS CONVENTIONAL CAUSTIC PEELING AND THE EFFECT ON WASTE DISPOSAL 129

Joseph W. Cyr

DRY CAUSTIC PEELING OF TREE FRUIT TO REDUCE LIQUID WASTE VOLUME AND STRENGTH 137

Dr. Jack W. Ralls, Walter A. Mercer, Robert P. Graham,
Mark R. Hart, and Harry J. Maagdenberg

PRODUCTION OF POTATO STARCH WITHOUT WASTE 169

Roy Shaw and W. C. Shuey

ECONOMIC ANALYSIS OF ALTERNATIVE METHODS FOR PROCESSING POTATO STARCH PLANT EFFLUENTS 185

R. L. Stabile, V. A. Turkot, and N. C. Aceto

CONTINUOUS TREATMENT OF CORN AND PEA PROCESSING WASTE WATER WITH FUNGI IMPERFECTI 203

**Dr. Brooks D. Church, Dr. Harold A. Nash, Dr. Eugene E.
Erickson, and Willard Brosz**

CANNERY WASTE TREATMENT WITH RBC AND EXTENDED AERATION PILOT PLANTS 227

R. J. Burm, M. W. Cochrane, and K. A. Dostal

CANNERY WASTE TREATMENT BY LAGOONS AND OXIDATION DITCH AT SHEPPARTON, VICTORIA, AUSTRALIA 251

Dr. C. D. Parker and G. P. Skerry

BIOLOGICAL TREATMENT OF CITRUS PROCESSING WASTEWATERS 271

Dr. F. A. Eidsness, J. B. Goodson, J. J. Smith, Jr.

TREATMENT OF MEAT PACKING WASTE USING PVC TRICKLING FILTERS . . 287

Darrell A. Baker and James White

DEHYDRATION OF CATTLE RUMEN AND WHOLE BLOOD 313

Dr. Donald J. Baumann

WATER AND WASTE MANAGEMENT IN POULTRY PROCESSING 323

Dr. W. M. Crosswhite, R. E. Carawan, and John A. Macon

REMOVAL AND RECOVERY OF FATTY MATERIALS FROM EDIBLE OIL AND FAT REFINERY EFFLUENTS 337

W. C. Seng

BIOLOGICAL TREATMENT OF HIGH BOD YEAST WASTES 367

Thomas P. Quirk

THE BETTER WHEY--A DILEMMA 409

Sidney Boxer

MEMBRANE PROCESSING OF COTTAGE CHEESE WHEY FOR POLLUTION ABATEMENT 413

Dr. Robert L. Goldsmith, Dr. David J. Goldstein, Bernard S. Horton, Sohrab Hossain, and Dr. Robert R. Zall

ACTIVATED SLUDGE AND TRICKLING FILTRATION TREATMENT OF WHEY EFFLUENTS 447

Thomas P. Quirk and Joseph Hellman

METHANE FERMENTATION OF WHEY 501

Dr. C. D. Parker

STATE OF THE ART OF DAIRY FOOD PLANT WASTES AND WASTE TREATMENT 509

Dr. W. James Harper and John L. Blaisdell

ANAEROBIC-AEROBIC PONDS FOR TREATMENT OF BEET SUGAR WASTES . . . 547

Dr. William J. Oswald, Dr. Clarence G. Golueke, Dr. Robert C. Cooper, and Ronald A. Tsugita

STATE-OF-ART SUGARBEET PROCESSING WASTE TREATMENT 597

James H. Fischer and E. H. Hungerford

PRINCIPLES OF NUTRIENT CONTROL FOR AGRICULTURAL WASTEWATERS . . 605

Dr. Raymond C. Loehr

OXIDATION DITCH TREATMENT OF MEAT PACKING WASTES 617

Dr. W. L. Paulson, D. R. Kueck, and W. E. Kramlich

SOLID WASTE MANAGEMENT IN THE FOOD PROCESSING INDUSTRY 637

Henry T. Hudson

REGISTRATION LIST 655

SYMPOSIUM OBJECTIVES

by

James R. Boydston*

We are most pleased with the response you have shown to this our Second National Symposium on Food Waste Treatment Research. As many of you know, we started this program last year in Portland with a 3-day symposium primarily concerned with reporting on projects of the Research and Demonstration Grant Program of the Federal Water Quality Administration. The enthusiasm shown there and the comments we received prompted us to schedule these conferences on an annual basis. This Second National Symposium has already been expanded to include air pollution and solid wastes and the meeting had to be extended to four days to provide room for all of the technical papers.

The purpose of these symposia is to provide a forum for formal and informal discussions among all individuals involved in the treatment of wastes from the food processing industry. The registration shows that attendees at this symposium are administrative, professional, and technical people from regulatory agencies, universities, engineering consultants, and private industry. We believe there is no substitute for direct personal contact such as this to determine research needs and to disseminate information on new research findings.

The food processing industry is one of the major sources of organic industrial wastes. This industry, perhaps more than any other, has a wide variety of types of plants due to the many segments of the industry--ranging through fruit and vegetable canning and freezing; seafood processing; the beverage industry, including soft drinks, breweries, wineries, and distilleries; dairy industry; beet and cane sugar; and grain milling--to name a few. The treatment requirements for wastes from these segments are extremely varied.

All industries are currently facing increasing requirements for waste treatment. Waste discharge permits are now required under the Refuse Act of 1899 and effluent standards will be imposed. Because of these changes, there is increasing need to develop better methods of treatment, to develop by-product recovery methods, to change plant processing to reduce waste at the source in the plant, and to develop higher degrees of treatment to permit water reuse. To be of value, information on new methods to accomplish these goals must be available to those who can make use of it as fast as possible.

---

*Chief, National Waste Treatment Research Program, Pacific Northwest Water Laboratory, Water Quality Office, Region 10, U. S. Environmental Protection Agency, Corvallis, Oregon.

The Environmental Protection Agency conducts an active national research program directed to identifying efficient methods for the treatment of wastes from the food processing industry. We look upon the dissemination of research results as important as the research itself. Reports are published for all in-house and extramural grant projects and made available for public distribution. We provide technical assistance to regulatory agencies and to industry directly. We feel, however, that this symposium provides an excellent opportunity for distributing information on new research, development and demonstration findings since it gives the opportunity for direct personal review and discussion of these projects. Your interest will insure continuation of these annual conferences.

This meeting should not be construed as a government water pollution research meeting. It is co-sponsored by your industry association, National Canners Association, and includes technical discussions in the fields of air, water, and solid waste, and includes reports of research and development undertaken by industry, universities, engineering consultants, and the Federal Government.

ENVIRONMENTAL QUALITY CONCERNS OF THE FOOD PROCESSING INDUSTRIES

by

Alvin H. Randall

INTRODUCTION

Last year, Mr. James R. Boydston of the Pacific Northwest Water Laboratory, in opening the First National Symposium on Food Processing Waste, stated, "This meeting beginning today marks a milestone, I think, in the national program of research and development of water pollution control methods for the food processing industry ... it truly represents a cooperative coordinated effort between industry and government to mutually solve troublesome water pollution problems."

Reports coming to me from the Association staff stated that the First Symposium was most productive. The intensive planning for this Second Symposium and its comprehensive coverage of research on food waste will add immeasurably to our knowledge of the treatment and management of food waste materials.

Speaking as President of the National Canners Association and for its staff and members, we are pleased and honored to be recognized as a co-sponsor of this the Second National Symposium on Food Processing Wastes.

As both food processor and citizen, I recognize the importance of the subject matter you will be discussing. Today, we are all concerned in varying degrees about our environment. What is the actual state of our environment? What corrective actions must be taken now, and what long-range planning should be undertaken? Although the sociological answers must come from everyone, the technological answers and the implications and costs for achieving these levels of environmental quality must, for the most part, come from you the scientists.

We deeply appreciate the excellent cooperation and communication which exists between the Association, its staff and committees, and the various staff members of the Federal Water Quality Office. This is a unique and fruitful relationship for which we are grateful and which could serve as a model that should prevail between all of industry and all other agencies of government.

For a number of years, the staff of the Association has worked closely with state and federal agencies on the development of water quality

---

*President National Canners Association, Washington, D.C., And Executive Vice President, United Flav-R-Pac Growers, Inc., Salem, Oregon criteria and the development of technical and economic data needed for establishment of reasonable water quality standards. Information on the nature and volumes of food processing wastes has been developed and distributed to industry members and all levels of government.

Other relationships between the Association and Federal Water Quality personnel have included the administration and performance of research grants and contracts concerned with treatment and management of food wastes. These cooperative efforts have been of great benefit to the industry. Not only has new and urgently needed technical information been developed, but the demonstration aspects of the various projects have filled a need which would not otherwise have been satisfied.

In the performance of these projects, jointly financed by the Association with the Federal Water Quality Office, it has been the pleasure of the Association staff and committees on environmental problems, to know and work with Mr. Allen Cywin, Director of Applied Science and Technology; and within that Division, Mr. William Lacy and Mr. George Keeler, both of the Industrial Pollution Control Branch. Equally enjoyable and helpful has been our association with Mr. James Boydston, the Symposium Chairman, and Mr. Kenneth Dostal of the Pacific Northwest Water Laboratory. There are many other names which could be added to this list. All have been unstinting in their efforts to assist in the design and performance of research and development programs which are deemed important to the food processing industry both now as well as in the future.

Over and above the high regard and respect we have for the knowledge and efficient manner in which these men handle their responsibilities, we appreciate the friendly and personal interest they have shown in the problems and the welfare of the food industry as a whole.

FOOD INDUSTRY CONCERNS AND COMMITMENTS

The membership of the National Canners Association shares in the national concern for the quality of the physical environment. The basic ingredients for the industry are wholesome raw foods and adequate supplies of clean water. We believe that environmental control is a complex and continuing process which requires constant searching for improved solutions to the problems which arise from waste materials generated in food growing and processing. We believe that standards to assure the quality of the environment, exclusive of those measures necessary to protect public health, must be achieved in an orderly and logical manner. Precipitous and unnecessary actions should not be initiated. These could disrupt the economy of the Nation and interfere with our industry's first responsibility to grow, process, and distribute wholesome and nutritious foods for the consumers of the world.

Perhaps the best way to capsule the food industry's viewpoint is to read to you a formal resolution adopted by the National Canners Association at its Sixty-Fourth Annual Convention, held a few weeks ago.

> "The canning industry continues to recognize its responsibility for the development of lawful solutions to pollution problems, and that a closely coordinated industry effort, including continuing research at both the laboratory and plant level, is the most efficient and economical means of developing effective pollution control. The interdependence of farmers, processors, workers, and the communities in which they reside -- the magnitude, seasonal nature, and interstate character of the food industry's pollution problems -- and the overriding interest of the consuming public in a wholesome, abundant, and economical food supply -- make it imperative that Federal, State and local authorities not only establish realistic guidelines and objectives, but that they also participate actively and substantially in the development of solutions to these problems. In the necessary overall effort to promote recognition by the public and by industry and governmental leaders that effective pollution abatement programs must proceed in an orderly, logical, progressive manner that will afford adequate time for the development and implementation of technology, any additional needed research, pilot-scale testing, treatment plant construction and economic adjustment, the industry endorses cooperative efforts to establish standards that are both practicable in each specific problem area, and which avoid blanket requirements that may in their impact be unrealistic, unnecessary, or unreasonable. The canning industry endorses the establishment of the Federal Environmental Protection Agency as a forward step and pledges its cooperation with that agency. Necessarily, the producers and processors of our food supply must be allowed to continue to expand the production of food for a hungry world, while at the same time adjusting to the demands of protecting our environment."

This Symposium, in addition to dealing with the research and technical aspects of specific pollution control problems, and their resolution, affords us the opportunity to present to the public in general, and in particular, to the Environmental Protection Agency (EPA) and its administrators, matters of concern in executing federal programs both in the immediate future and long range. Therefore, I will outline our major concerns in the hope that this will create a platform for present and future discussion of the issues. We believe that only in a continuing dialogue can we each profit from the concerns and convictions of the other.

QUESTIONS ON WATER QUALITY STANDARDS

The Federal Water Quality Act of 1965 recognized that different rivers and bodies of water have different uses and problems and that pollution control efforts should be tailored to meet water quality standards and beneficial uses prescribed for each of these waters. Most of the states have standards which are based on assigned beneficial uses to each stream or section of streams. In these cases, all control efforts work back from these water quality standards.

We understand that a change in pollution control philosophy is imminent in that national effluent standards will be established through federal legislation or regulation. We are concerned that rejuvenation of the Refuse Act of 1899 is a step in that direction and that this could be contrary to a sound, logical, and progressive approach to resolution of this pollution problem. We hope that some of my following remarks will clarify this position.

We would have to agree that there are probably cases in which water quality standards alone are not enough. Our primary concern with any future effluent regulations that may set quality criteria for liquid wastes being discharged from industrial sources, is that the costs of compliance be weighed against the benefits obtained. Where the economic impact will unreasonably distort the local economy, will it be possible to regard water quality as the basic objective rather than to adopt limitations based solely on discharge characteristics and loads? Will the economic impact be taken into consideration in forming regulations? Will each case or situation be submitted to cost-benefit analyses?

We heartily agree that there should be no discharge in any stream of the country, which would cause harm to human health or produce an undesirable irreversible effect on environmental quality. In such cases, cost should not be a factor for consideration. Will the program that is being evolved for pollution abatement be able to keep, as its primary objective, the maximizing of net benefits to society?

For example, wastes from the preparation of foods are not considered toxic in the sense that their ingestion would be detrimental to humans or animal life. Will the yardstick used to measure the impact on the environment of the specific quality or characteristics of each effluent also recognize these differences?

We believe that M. A. Bernarde, in his Our Precious Habitat, has suggested a concept which is realistic and which must prevail, for a time, if the Nation's economy is to remain viable:

> "The present state of development of our technological society makes it mandatory that we accept a certain degree of pollution. We are still far from developing new methods of liquid-waste disposal that will make dumping in rivers obsolete. The fact is that industry and residential communities alike would be forced to shut down if unified public opinion demanded pollution-free waterways. It is, therefore, in the best interests of the community to support research investigations aimed at discovering the degree of waste a stream can adequately tolerate without the initiation of noisome

> (malodorous) conditions. Decisions as to what constitutes a tolerable degree of pollution must be reached after considering the water's natural purification capacity and the purpose for which it is to be used."

We are concerned that demands are being made for removal of higher and higher levels of organic pollutants, and that such demands may not be based on scientifically determined needs for higher-level treatment but rather on political or other expedient considerations. Can and will evaluations be made of the cost-benefit ratio between the disproportionate energy input required to obtain these higher and higher levels of treatment of organic pollutants and the total impact on the environment resulting from creation of these increasing energy requirements?

We feel that it is extremely important that priorities be established within the area of pollution abatement itself, just as the Nation as a whole must establish priorities between pollution abatement and competing goals and objectives. In emergencies, and in the case of harm to human health, there is, of course, no alternative to immediate abatement action. But in all other cases, priorities must be established. We believe the result must be a carefully planned and well-integrated approach for both immediate and long range needs. Recognition should be given to the fact that abatement of pollution is not an all or nothing proposition. No longer should we have a program of frequently-changing objectives, but one which moves with dispatch upon pressing needs and establishes a well coordinated, long-range program that will create the least amount of economic upheaval.

ECONOMICS AND ENVIRONMENTAL QUALITY

The Economic Environmental Policy Advisory Committee has submitted to the Honorable Maurice H. Stans, Secretary of the Department of Commerce, a report entitled Economic Policy Issues and Environmental Deterioration. We feel this document well describes our various concerns and we would encourage, in the execution or enforcement of abatement programs, both immediate and in the future, that these considerations will be applied. Use of these criteria and guidelines, by those directly responsible for execution of all programs would allow the most efficient and equitable solution to the pollution problem. Although it may be desirable from the standpoint of enforcement, to seek a simple overall solution, it is apparent that to avoid wasting manpower and money, abatement efforts must utilize these criteria and guidelines. Otherwise abatement efforts cannot be kept on an economically viable course. We would further encourage incorporation as regulations, for those making judgments on specific field installations, the six principles of paramount importance in the report of the Economic Environmental Policy Advisory Committee. The principles I refer to are as follows:

"First, like other national objectives, pollution abatement involves a marshalling of economic resources that are limited. This requires a choice or allocation of resources between competing objectives -- in other words, a recognition of sensible priorities and a recognition of trade offs. These priorities and trade offs will be influenced significantly by the time span during which the problem is treated.

Second, the overriding criterion to be used both in determining the proportion of national resources to be directed toward pollution abatement and in determining how costs should be distributed between the public and private sectors is to seek the path or methods leading to the maximum net social benefit (or conversely to the lowest net social cost).

Third, in determining the lowest cost solution, pollution abatement objectives must be subjected to comprehensive yet penetrating cost-benefit analyses. In such analyses both costs and benefits must be viewed in their broadest framework. One of the striking aspects of the pollution problem and a serious limitation, however, is the dearth of adequate factual information. Clearly, the nation has an obligation to move as expeditiously as possible toward the development of a body of information relating to the pollution problems that would enable policy makers and responsible government officials to make cost-benefit analyses in an intelligent manner.

Fourth, major reliance should be placed on the competitive market system and its demonstrated capacity as an efficient allocator of resources in seeking the lowest cost solution to pollution. Every effort should be made to tap and implement the ingenuity, initiative, and incentives that are an intrinsic part of the system.

Fifth, departures from the principle of major reliance on the competitive market system may be dictated by three factors: (1) crises situations; (2) research and development needs; and (3) extreme hardship cases.

Sixth, recognition of the above principles leads naturally to certain criteria that can help evaluate proposed methods of financing pollution abatement and also the relative emphasis that should be placed on the private and public sectors. In the realization of these principles, the fundamental economic criteria that has guided the development of this report is that the costs of pollution abatement should generally be borne by the private producer/consumer sector. Ultimately, the prices of products and services flowing into the economic stream must reflect these full costs."

CONCERNS ABOUT LONG-RANGE RESEARCH

It is apparent that present problems and conditions will not be totally eliminated because of the limitations of existing technology and the limitations inflicted by economic pressures. There is a need for on-going research geared for long-range study programs. We would like a better and clearer understanding of the EPA's policy and funding for both short-term and long-range research. We have a deep concern that assignment of regional laboratories to monitoring programs will result in limited and meager research budgets rather than greatly expanded research programs that must meet both immediate and future needs. It has been most disappointing over the past few years to see an erosion of research funds because of reduced priorities in this area, and a resultant failure to expand the regional laboratories to their full potential. This is a great loss, not only for the present but also for the future decade. We in the industry recognize that there are numerous technological barriers to the solution of some of our problems and we strongly urge increased research effort to find the practical answers. It has been estimated that on the average approximately ten years are required for new research to have full and applied commercial realization.

We hope that future research funding for the regional laboratories can follow the comments of the National Goals Research Staff: "To the extent that society insists that basic scientists do work that is more relevant to present social needs -- scientists will be less able to work where nature appears willing to answer their questions. They may be required to work on relevant questions that perhaps cannot be answered at all at present, or can be answered only with uneconomic use of resources. Thus excessive efforts to make science more productive in terms of immediate social goals may actually make it far less productive in the long run."

This concept further shows the need to avoid broad-based applications of restrictions. Rather, each water system and each case should be evaluated on its own unique conditions. In this connection, we believe that government should sponsor research which will study our environment not only from the standpoint of eliminating unnecessary pollutants but also with regard to learning how to utilize non-toxic materials in the environment. We, as food processors, feel that the future may find us dependent on learning to farm our streams, lakes, and oceans. An acceptable concept, in our opinion, would utilize non-toxic, organic wastes, such as those from the processing of seafoods, fruits and vegetables, for enrichment of the marine environment to the end that a greater abundance of fish and aquatic plants are produced. To what extent is there planning and funding to expand our knowledge of the use of these materials in the aquatic environment?

Most of the deep ocean is, in many respects, a vast desert that yields very small quantities of food life in comparison to the potential with suitably provided nutrients. Can we be assured that plans are being made for research to determine acceptabe ways of discharging food processing wastes and, in fact, municipal food wastes to the oceans in order to yield a more abundant fish life?

I have suggested in preceding comments that although elimination of many compounds presently discharged to our waterways should be excluded or reduced, there is the possibility that in many places we can learn how to better manage what are presently considered as objectionable compounds, such as phosphates and nitrates, in these waterways. To this end, we hope that a major stream, having all the variations that could be considered typical of the different cross-sections of life, could be studied in depth to achieve this more desirable management goal. In such a stream basin, would it be possible for the federal government to subsidize, immediately, the cost for the best technology available for elmination of pollutants in the effluent? This would permit us to learn whether, indeed, the programs being projected for the entire country will net all the benefits we anticipate. The results could show that a greater effort should be made to perfect utilization of the various residuals discharged to streams by adding to the stream other materials to achieve the "fish hatchery" approach.

Previously, I briefly mentioned aquatic plants. We believe that a broad field of study should be instituted on the use of aquatic plants to remove undesirable materials and nutrients from streams and lakes by the eventual harvest of these plants as a potential food supply. In too many areas, marshes and swamps have been drained within which normal growth of aquatic plants was performing a very valuable service. We believe that it is time to give consideration to re-establishing such conditions in rivers and lakes. Where this could be established under proper management, it may be possible to gain even more benefit than came from the original marshes. Consideration could be given to harvesting the aquatic growths, thus short-cutting nature's cycle of normally returning the nutrients to the environment when the plants die. Under proper water management, a crop that is beneficial to society may be harvested. We hope that fertile areas, such as these, will receive attention and funds for research in the EPA regional laboratories and in universities. If so, then the next decade will be able to benefit from today's progressive thinking on managing our waterways.

OTHER INDUSTRY CONCERNS

It has been recognized that, basically, pollution is a people-problem. Government spokesmen have assured us that industry is not to be made the whipping boy in pollution abatement programs. Yet, we understand that the Federal government has said that no industrial representatives and only conservationists should be placed on water quality and water resources boards. We would be greatly disturbed if recognition is not given to the fact that one person may be both an industrialist and a conservationist. Surely, it can be recognized that one who totally ignores conservation, or industry's welfare, or any other factor, is equally unacceptable.

As individuals and as an industry, we urge abandonment of the "crash" psychology that seems to believe that all social ills can be cured by massive doses of "instant money" and that massive government spending will produce an instant pollution-free tomorrow. How can we obtain a well-informed people who, given an understanding of the total picture, will, in turn, prevent improper legislation arising from superficial knowledge, lack of study, and subjective irrational thinking? We would like recommendations on improving communications between government and industry, and, in particular, to the general lay public. As an industry and as individual citizens what should our role be in assuring that all decisions are based on facts -- not conjectures, arbitrary opinions, or emotions? How do we avoid confrontation and still maintain economically-viable programs that do not cause major industry and employment dislocations?

The food processing industry is concerned with the frequently-changing and unpredictable nature and degree of state and federal environmental control programs. Decision making by the industry, leading to compliance with present and probable pollution abatement requirements, is made difficult on both a regional and national basis by these major uncertainties. In preparing information for the National Industrial Pollution Control Council, we have listed eight environmental matters of general concern to the food processing industry and would appreciate EPA's candid comments on each of these issues.

A. Establishment of standards which take into consideration the nature and treatability of each type of waste and which are flexible depending on the degree of treatment needed, in each river-basin or regional area.

B. Establishment of a relatively uniform system of enforcement to avoid gross inequities which could affect different members of any given segment of industry.

C. State and Federal regulations that are changing so rapidly that we are never sure we are complying with latest requirements in all phases of pollution control. It appears that the criteria established by different states vary and this presents problems in establishing and projecting budget requirements for plans to satisfy all codes.

D. The need for cooperative industry-government efforts to organize and disseminate to the public, industry, and all levels of government, an orderly, logical, and progressive schedule for pollution abatement. The schedule should include a timetable with goals for achieving an improved environment. The schedule must also provide time for needed research, for trial and error testing, for construction of the treatment plant or other abatement facility, and for economic adjustment.

E. The need for public affairs programs to adequately and objectively inform all concerned about the realities of environmental quality control and the total consequences of extreme measures which may not be necessary now, if at all.

F. The related need for a general understanding of the total pollution problem, which involves the whole population in all of its activities and which cannot be eliminated simply by imposing strict controls on industry.

G. The non-productive costs of managing wastewaters and solid wastes may, as a result of sudden changes in the economic marketplace, cause an adverse tipping of the balance against older or obsolescent plants. As an example, the Department of the Interior regulation, concerning grants for treatment plant construction*, can arbitrarily, without taking into consideration other social and economic benefits, cause unnecessary economic hardship.

H. Many food processing plants presently utilize municipal treatment facilities to handle waste discharges from the preparation of these foods. Due to possible increasing pressure to upgrade the effluent quality, industry may be refused this service and may find it economically or technologically difficult to continue to be a generator of economic benefits within the community.

In conclusion, we cannot over-emphasize the excellent cooperation existing among the various branches of the government dealing with research, and the Association and its membership. This communication is invaluable from many standpoints and emphasizes the need for this same approach all across industry. It should be amplified and improved wherever possible in all industries. We would appreciate comments as to how this relationship could be expanded and enhanced for our own area. Would it be appropriate for industry and government representatives to meet and explore developments in this area?

We are particularly interested in realizing this same relationship existing with our government groups that are involved in the environmental area. We recall that the National Technical Task Committee on Industrial Wastes was an important adjunct to industry and government and that a great deal was lost upon its discontinuation. Public clamor raises a furor on single issues. We, industry, and government, must be dedicated to an on-going program. The greater the inter-change of information and communication, the better will be the possibility of realistic and economic programs for improving the environment.

---

*Federal Register, Vol. 35, No. 128, pages 10756 - 10757, July 2nd, 1970.

EPA'S INDUSTRIAL POLLUTION CONTROL PROGRAM

by

Dr. Stanley M. Greenfield*

President Nixon has said "We are determined that the decade of the 70's will be known as the time when this country regained a productive harmony between man and nature." Our problems with the environment have become critical and we must act now if we are to preserve this harmonious relationship with nature. We have already taken major significant steps to reverse our degradation of the environment. I am most pleased to report to you today on the progress made by the Government to date on this endeavor and to discuss our needs and plans for the future.

Our problems with pollution are not new. Indeed, man has abused the environment as long as mankind has been on this planet but in recent years population growth has exceeded the capacity of our air and water to absorb the municipal and industrial pollutants and we can no longer turn our backs on the problems we have created. In the past we have not fully appreciated what we are doing to our air and water resources. We have ignored the fact that these are finite and limited resources, although, our demands upon them have increased at alarming rates. Consider that since 1900 the population of the United States has doubled but in this same period of time the needs of industry for water have increased ten times. It is estimated that the next doubling of the world population will occur in 35 years rather than 70 and we can anticipate similar industrial growth. It is clear that we must take immediate action to restore the quality of environment we expect and demand.

We have made progress. New technology has been developed for treatment of air pollutants and liquid wastes but some times the treatment of one has been to the detriment of the other. Further, our population and industrial growth have outstripped our technology in many cases and in spite of the installation of required treatment facilities, we have found a decline in stream quality in many parts of the United States. Recognizing the need for a better directed effort to control all forms of pollution, President Nixon last year through reorganization created the Environmental Protection Agency. This was done to consolidate all environmental pollution control activities of the Federal Government into a single agency. EPA consists of the water pollution control activities formerly in the Department of the Interior, the air pollution control activities and solid waste function of the Department of Health, Education, & Welfare, and pesticides and radiation control activities formerly in a number of different agencies.

---

*Assistant Administrator for Research & Monitoring, U. S. Environmental Protection Agency, Washington, D. C.

Let me speak for a moment on the reasons for the reorganization to form EPA. In the past the organization of the Federal Government to deal with pollution has suffered from two obvious problems. First, for many particular kinds of pollution, a number of different Federal agencies have had overlapping or closely related responsibilities. For example, three Federal Departments, Agriculture, HEW, and Interior were directly involved in regulating pesticides. And similarly, a number of agencies have some responsibilities for radiation problems. Second, the organizational basis for controlling pollution was not consistent or adequate. The two largest agencies, the Federal Water Quality Administration and the National Air Pollution Control Administration, were organized on the basis of the media--air or water--through which the pollutants traveled. The other pollution control programs on the other hand generally were organized on the basis of particular pollutants, pesticides, radioactive materials, and solid wastes. Confusion has resulted about the extent to which air and water pollution control agencies were responsible for radioactive materials and pesticides when these materials appear in air or water.

The programs to deal with pesticides and radiation were developed in part because these two kinds of pollutants did not fit neatly into the categories of air and water pollution. Pesticides and radiation are found in both air and water and on the land. We can expect that pollution control problems of the future will be increasingly of this kind. They will involve toxic chemicals and metals which are found in all media and which run counter to the previous type of organization of air and water pollution control in the government.

Some pollution problems remain unrecognized because of gaps in agency jurisdiction or because no one agency had clear lead responsibility. The Environmental Protection Agency will overcome this handicap because of its broad responsibility for environmental pollution control.

Another problem of past Federal organization has concerned the fact that in some cases agencies which have responsibility for promoting a particular resource or activity also have responsibility for regulating the environmental effects of this activity. Two clear examples of this potential conflict of interest were agriculture's regulation of pesticides and the atomic energy's regulation of radiation levels. Regardless of how good a job these agencies did, the public was increasingly questioning the assignment of promotional and regulatory powers in the same agency. The Environmental Protection Agency has been given these regulatory functions and this should restore public confidence in our ability to control pollution from these sources.

The existence of a unified pollution control agency will clarify the Federal Government's relations with state and local governments and with private industry. More than half the states already have a single agency responsible for all forms of pollution. A number of others are considering establishing such an agency.

The reorganization was affected by an Executive Order of the President creating the Environmental Protection Agency. Under the law, such a reorganization plan cannot create any new legal authorities or functions, therefore, EPA simply functions under the same legislation which originally created its constituent parts, however, this new agency will be able to perform the existing functions better and as new legislation is provided will be able to undertake new activities not easily done under the previous structure.

The key functions in pollution control are standards setting and enforcement. Standards provide the goals of the control program, the basis for enforcement actions, and the measure of the program's progress. Standards should be based upon the total amount of a given pollutant to which humans or some element of the environment are exposed even though the standards apply to a particular medium. Lead, for example, may reach humans through the air or the water but the key question is how much comes from all sources together. The organization of EPA will permit standard setting for pollutants which cut across media lines.

The enforcement function will be improved in several respects. The new agency will be able to examine the path of a pollutant through the total environment and determine at what point control measures can be most effectively and efficiently applied. For example, it may be that in some cases a pollutant can best be controlled by limiting its entry to the environment as has been done with pesticides.

Research will be similarly strengthened. Research on the health effects of pollution will be able to take into account the exposure to a given pollutant from all sources. Research on ecological effects must consider the interrelated parts of the environment and the impact of man's activities. It will be far easier to conduct ecological studies in an agency which is not limited to one particular medium or pollutant. Likewise, waste treatment research may now consider integrated systems to control air and water pollution and the ultimate disposal or recycling of solid wastes.

Briefly, these are some of the reasons for the President's formation of EPA and its more efficient ways of functioning as a unified agency. The creation of EPA represents a major step forward in streamlining the Federal Government's activities in pollution control. It cannot be the ultimate step, however, in a dynamic society such as ours. Much remains to be done.

In his message on the environment last month the President asked Congress to take additional steps to further strengthen our pollution control activities. He has requested a 1972 budget of $2.45 billion for the programs of the Environmental Protection Agency--nearly double the funds appropriated for these programs in 1971. The funds will provide for the expansion of air and water pollution, solid waste, radiation, and pesticide control programs, and for initiating new activities in these programs.

Last year the President requested new legislation to broaden the water quality standards requirements but Congress did not act on this request. The Government did move ahead, however, to make use of existing authorities through the Refuse Act of 1899 to require discharge permits as announced in December. The President has again asked this year for reforms in the water quality laws regarding effluent standards which would be administered by EPA. Water quality standards now are sometimes imprecise and unrelated to specific water quality needs and these do not provide a good basis for enforcement. The President has proposed that the Federal-State Water Quality Program be extended to cover all navigable waters and their tributaries, ground waters, and waters of the contiguous zone. He has requested that the standards be revised to impose precise effluent limitations on both industrial and municipal sources. He has asked for standards to regulate the discharge of hazardous substances, similar to those included in the Clean Air Amendments of 1970. The President has asked for legislation on standards to require that the best practicable technology be used in new industrial facilities to insure that water quality is preserved or enhanced.

In the matter of pesticides, the President has asked for new legislation which would provide for a registration procedure designating pesticides for general use, restricted use, or use by permit only. Pesticides designated for restricted use would be applied only by an approved pest control applicator. Pesticides designated for use by permit only would be made available only with the approval of an approved pest control consultant. This would help to insure that pesticides which are safe when properly used will not be misused or applied in excessive quantities. The requested legislation would authorize the administrator of EPA to permit the experimental use of pesticides under strict controls when he needs additional information concerning a pesticide before deciding whether it should be registered. This requested legislation would also authorize the administrator to stop the sale or use of and to seize pesticides being distributed or held in violation of Federal law.

The President has also asked for new legislation concerning toxic substances. As we have become increasingly dependent on many chemicals and metals, we have become acutely aware of the potential toxicity of the materials entering our environment. Each year hundreds of new chemicals are commercially marketed and some of these may pose serious potential threats. Many existing chemicals and metals, such as PCB (polychlorinated biphenyls) and mercury also represent a hazard. We need better methods to assure adequate testing of chemicals to avoid environmental crises of the future. The President has proposed to Congress that the administrator of EPA be impowered to restrict the use or distribution of any substance which he finds is a hazard to human health or the environment. The President has requested legislation to authorize the administrator to prescribe minimum standard tests to be performed on these substances.

One of the other areas discussed in the President's Message on the Environment last month included the problem of ocean dumping. He recommended a national policy banning unregulated ocean dumping of all materials and placing strict limits on ocean disposal of any materials harmful to the environment. He recommended legislation to require a permit from EPA for any materials to be dumped into the ocean, estuaries, or great lakes and to authorize the administrator to ban dumping of wastes which are dangerous to the marine ecosystem. I believe the key words here are "unregulated ocean dumping," and "wastes which are dangerous." It has been suggested that much of the ocean may be a biological desert and some fertilization through the discharge of controlled amounts of wastes might increase the productivities of the marine environment. There is an obvious need for research to define the optimum levels of waste discharged to enhance the productivity. Obviously, waste overloads will degrade the water quality.

These proposals requested by the President in his Message on the Environment delivered to Congress last month have not been enacted into law but I believe they reflect the mood of Congress and the American public for stricter control of pollution in the environment.

Mr. Ruckelshaus, the Administrator, EPA, has said that we now have all the tools to do the job. We have the organization in the form of EPA and we have the three essentials of support. We have the support of the Administration, the support of the Congress, and the support of the American Public. We have begun a concerted fight to restore the quality of the environment.

One of our primary goals is to achieve installation of adequate treatment facilities for all municipal and industrial sources of waste within the next five years. To accomplish this will require the coordinated efforts of all aspects of society.

The Federal Research and Development Program is an essential key to the accomplishment of these goals.

The goal of any research program is to provide through technical investigation the criteria upon which decisions can be based to solve the problem. In the case of industrial waste treatment research, these criteria may be design criteria for waste treatment facilities. Note that I did not indicate that the research need is to set treatment standards since this may involve social and economic considerations as well as technological requirements developed by us as researchers. It is our job, as I see it, to provide the best possible technical input upon which sound decisions can be based in the standard setting process.

President Nixon, in his message to Congress last month on a program for a better environment, said, "We have the technology now to deal with most forms of water pollution. We must make sure that it is used." This does not mean that our job is done, but rather that a solution is available. Obviously, Henry Ford's Model T provided a solution to the transportation problem but fortunately development of the automobile did not stop there.

The challenge we face is to develop tertiary or advanced waste treatment methods which will permit recycling and closing of the loop in water using industries, the development of in-plant processing changes to reduce waste discharge, and the development of processes to permit by-product recovery and reduce treatment costs. The food processing industry is an excellent example of how we intend to pursue a systematic research program. National responsibility for research on waste treatment in your industry has been assigned to the Waste Treatment Research Program in the Pacific Northwest Water Laboratory in Corvallis, Oregon. This laboratory is responsible for planning and conducting a coordinated research program utilizing the talent and resources of the Federal Government, universities, and the industry through in-house studies and extramural grant and contract programs.

The first step has been to obtain a definition of problems and research needs for the many varied segments of the food processing industry. This step is well under way. The University of Washington in Seattle was given an $18,400 grant to conduct a study on the status and research needs for potato waste waters. This project has been completed and a final report written. Other state-of-the-art studies nearing completion include seafoods, fruits and vegetables, dairies, sugarbeets, and beverages.

All of these studies cited were undertaken through the extramural grants program to define current practices in the treatment of wastes from various segments of the food processing industry and to pinpoint most urgent needs for additional research. With this "handle" on the problems, we can now direct available resources to those areas which most urgently need immediate solution. We have undertaken bench-scale studies with our own scientists and engineers and have funded similar research by universities and industry. Our research grants program has supported studies by university researchers on analytical methods, treatment processes, and the effects of pollutants on the receiving waters.

In 1966, Congress for the first time authorized grants directly to industry for the demonstration of new and improved techniques for the treatment of industrial wastes. This program from the outset has received enthusiastic response from your industry and many companies have participated in this cooperative Federal-Industry program. Many of these projects will be reported on during this conference. Let me just say that there are more than 50 currently active projects under our research and demonstration grant program with a total Federal grant involvement of over $10 million in the food processing industry alone. Some of these involve demonstration grants of several hundred thousand dollars to test at full-plant scale new and improved systems for the treatment of wastes.

This program will be continued but in order to make broader use of the funds available, more emphasis will be placed on the technical support of these projects, such as plant design, analytical studies, operation, and final report write-up. Participation in the construction of massive treatment facilities will be less likely to receive full grant support.

It has been our policy to support projects aimed at the development of in-plant changes to reduce waste loads and flow from the plant. Our support of the development of the dry caustic peeling of potatoes which can reduce the waste load by 50%, is an example of this.

We do not feel that conventional secondary treatment is the ultimate answer for water pollution control by industry. I fully expect that many segments of industry will ultimately have complete treatment systems with recovery of essentially all dissolved and suspended solids from waste streams permitting total recycle of water within the plant and with the sale or reuse of the recovered by-products.

Much is already being done to study methods for the recovery of by-products and to develop markets for them. Much of the solid waste from the food processing industry can be used for animal feed and we are confident that imaginative research will develop even more productive recoveries.

I have been speaking primarily about the water pollution control research program since this activity has received the major support emphasis in the past. However, the establishment of EPA now permits us to consolidate our research efforts within one program in all of the media affected by pollutants from industry. That is air, water, and land. Our reaearch effort can and will be extended to include methods to remove odors and particulates from air streams. Our research will extend to the ultimate disposal of solids separated from air and liquid streams so that we are assured that solution of one pollution problem will not create a second.

In line with our broadened research program to include air pollution and solid waste research, we intend to broaden our own research talent to include engineers and scientists familiar with industrial processes and others such as economists to permit us to truly look at the total picture of waste generation and treatment and control from an efficiency standpoint. I want us to be able to actively study and support changes in processes to eliminate waste at its source.

The development of new information is useless unless this is applied. This has been called technology transfer. It is our intent to make certain that new information developed through our research programs, particularly in the industrial pollution control field, is made available to you as rapidly as possible. We will do this not only through publication of reports but in symposia such as this and through direct technical assistance to the industry. We expect to work directly with you in the study of waste treatment problems and to make available through pilot-scale and full-scale demonstrations the latest techniques applicable to your industry.

The President has asked for a doubling of the budget for EPA this year and this level of increase will apply as well to the research and development program. Much work remains to be done if we are to find answers to our industrial pollution control problems that will be both effective and feasible but with your continued support and cooperation we will achieve our goals.

THE CLEAN AIR AMENDMENTS OF 1970

and

AIR POLLUTION ASPECTS OF THE FOOD AND AGRICULTURAL PROCESSING INDUSTRY

by

Dr. S. David Shearer*

INTRODUCTION

It is a real pleasure for me to be with you at your Second National Symposium. The three speakers preceding me have focused quite concisely upon the Environmental Concerns of the Food Processing Industry and upon the direction and character of the Industrial Pollution Control Program and Regional Activities of the Environmental Protection Agency.

I would like to bring to you this morning a brief review of the significant changes and amendments to the Clean Air Act which was signed into law by the President on December 31, 1970. Time does not permit me to cover in detail all of the new amendments but only those which would be of most direct interest to this group. In addition I will present to you some general qualitative information on the type and amount of air pollutants from certain types of food processing operations. Only the highlights of the latter will be covered here; however, the symposium proceedings will contain fuller details of my brief remarks.

CLEAN AIR AMENDMENTS OF 1970

The 1970 Amendments to the Clean Air Act encompassed a wide range of far reaching improvements designed to accelerate the restoration of our polluted air and to better preserve those portions of our country which are still blessed with acceptable air quality. These amendments provided for changes to the 1967 Clean Air Act as well as entirely new legislation in several areas. I have listed below most of the salient aspects of the 1970 Amendments:

1. Emphasizes, as the 1967 Act did, that the States will continue to have prime responsibility for control of Air Pollution including provisions to allow them to make the political and social decisions necessary to accomplish the requirements of the new amendments.

---

*Air Pollution Control Office, Environmental Protection Agency, Durham, North Carolina.

Preceding page blank

2. Increased financial and technical assistance to State and Local Air Pollution Control Agencies.

3. Increased monies for research and development directed toward improved and new pollution control techniques and processes.

4. Requirements for the establishment of national ambient air quality standards to be achieved in a definite time period. On January 30, 1971 the EPA published in the Federal Register proposed primary and secondary air quality standards for particulate matter, sulfur oxides, carbon monoxide, hydrocarbons, photochemical oxidants, and nitrogen dioxide.

5. Increased emphasis on comprehensive State-wide implementation plans to achieve the national standards. Such plans must include land-use and transportation control policies in addition to regulation of fuel storage and handling if necessary to achieve the standards within the prescribed time period. In addition, public hearings must be held before adoption of these State-wide plans.

6. Provides for the establishment of federal performance standards for new stationary sources of air pollution which reflect the use of the best system of emission reduction that has been adequately demonstrated.

7. Calls for the establishment of federal emission limitations for hazardous pollutants that may cause or contribute to an increase in serious irreversible or incapacitating illness.

8. Makes provisions for State and/or Federal officials to be able to enter industrial establishments for the purpose of copying records, making inspection of air pollution control equipment and to sample emissions.

9. Provides for several extensions and new provisions for control of pollution from new motor vehicles including assembly line testing in addition to provisions enabling states to require inspection and testing of motor vehicles in the hands of the general public if necessary as part of the state implementation plan to achieve national standards.

10. Allows the Administrator, EPA, to regulate, control, or prohibit the manufacture or sale of fuel or fuel additives if emissions endanger public health or welfare or impair the performance of motor vehicle or aircraft emission control devices.

11. Provides increased monies for the development of advanced automotive power systems directed toward the production of a pollution free passenger car.

12. For the first time the new amendments will require the federal government to establish emission standards applicable to emissions of any air pollutant from any class or classes of aircraft or aircraft engines which cause or contribute to air pollution which endanger health welfare.

13. Requires the federal government to not enter into a contract for procurement of goods, services, or materials with any industrial concern that is in violation of any part of a State-wide implementation plan to achieve air quality standards, new source performance standards, or national emission standards for hazardous air pollutants.

14. A final major new addition in the 1970 amendments is a provision whereby any citizen may bring suit in a Federal District Court against any industrial concern in violation of requirements of the Act or against State, Local, or Federal Agencies for failure to carry out the mandates of the Act.

I have included in the material which will be printed in the proceedings of this symposium flow charts and time schedules for compliance for five of the key section of the Clean Air Amendments of 1970. In addition, I have prepared a table of the proposed national air quality standards for the six pollutants mentioned in item 4 above.

Thus it can be clearly seen from the above listed items that with respect to air pollution control there is a firm mandate from the Congress that the States, Federal Government and Industry must do more and work harder to enhance and preserve our precious air resources.

PROPOSED NATIONAL AMBIENT AIR QUALITY STANDARDS

A. Sulfur Oxides (Primary*)

80 $\mu g/m^3$	Annual arithmetic mean
350 $\mu g/m^3$	Max. 24-hr. conc. (not to be exceeded more than once/year)

Sulfur Oxides (Secondary**)

60 $\mu g/m^3$	Annual arithmetic mean
260 $\mu g/m^3$	Max. 24-hr. conc. (not to be exceeded more than once/year)

B. Particulate Matter (Primary)

75 $\mu g/m^3$	Annual geometric mean
260 $\mu g/m^3$	Max. 24-hr. conc. (not to be exceeded more than once/year)

Particulate Matter (Secondary)

60 $\mu g/m^3$	Annual geometric mean
150 $\mu g/m^3$	Max. 24-hr. conc. (not to be exceeded more than once/year)

C. Carbon Monoxide (Primary)

10 mg/m^3	Max. 8-hr. (not to be exceeded more than once/year)

15 mg/m^3	Max. 1-hr. (not to be exceeded more than once/year)

Carbon Monoxide (Secondary)

10 mg/m^3	Max. 8-hr. (not to be exceeded more than once/year)
15 mg/m^3	Max. 1-hr. (not to be exceeded more than once/year)

D. Photochemical Oxidants (Primary)

125 μg/m^3	Max. 1-hr. (not to be exceeded more than once/year)

Photochemical Oxidants (Secondary)

125 μg/m^3	Max. 1-hr. (not to be exceeded more than once/year)

E. Hydrocarbons (Primary)

125 μg/m^3	Max. 3-hr. (6 a.m. - 9 a.m.) (not to be exceeded more than once/year)

Hydrocarbons (Secondary)

125 μg/m^3	Max. 3-hr. (6 a.m. - 9 a.m.) (not to be exceeded more than once/year)

F. Nitrogen Dioxide (Primary)

100 μg/m^3	Annual arithmetic mean
250 μg/m^3	24-hr. conc. (not to be exceeded more than once/year)

Nitrogen Dioxide (Secondary)

100 μg/m^3	Annual arithmetic mean
250 μg/m^3	24-hr. conc. (not to be exceeded more than once/year)

AIR POLLUTION ASPECTS OF THE FOOD AND AGRICULTURAL PROCESSING INDUSTRY

The processing of food and agricultural products for consumer uses involves a number of various processing steps such as collection, refining,

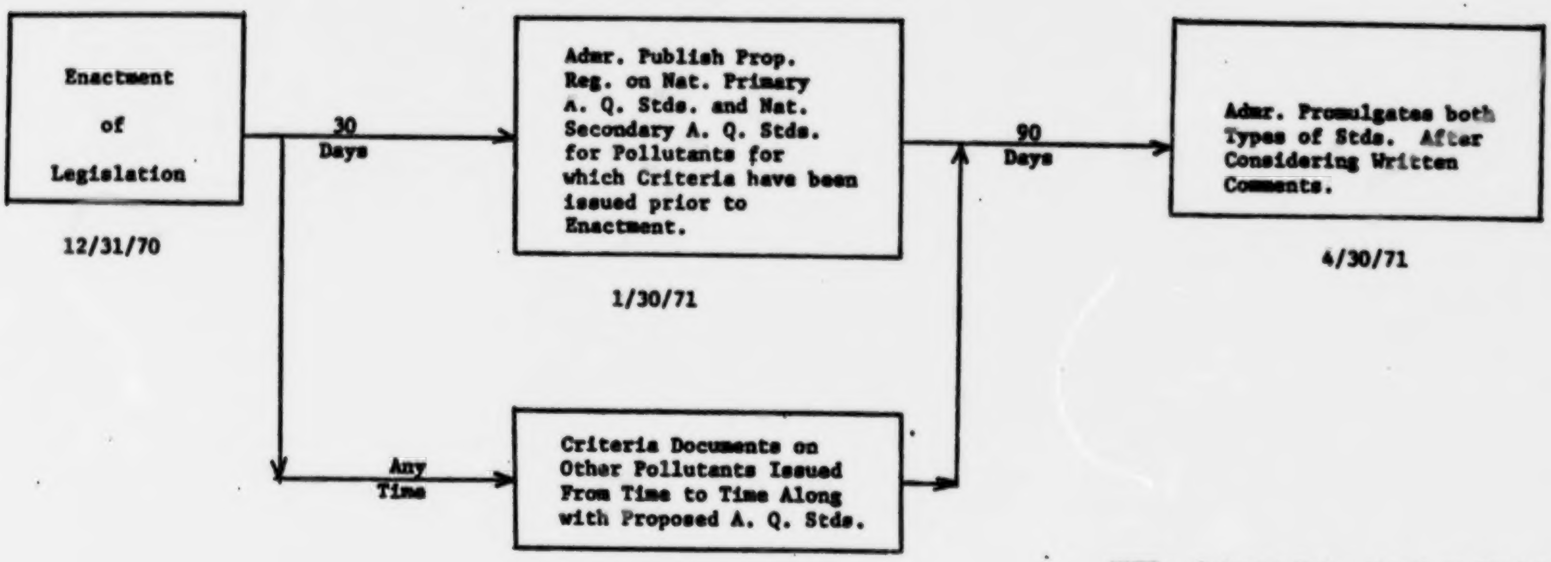
---

*Primary Standards are based on health considering a margin of safety.
**Secondary Standards are based on public welfare.

Attachment B

SECTION 109 - TIME SCHEDULE FOR NATIONAL AMBIENT AIR QUALITY STANDARDS

(CLEAN AIR AMENDMENTS OF 1970 - PL 91-604)

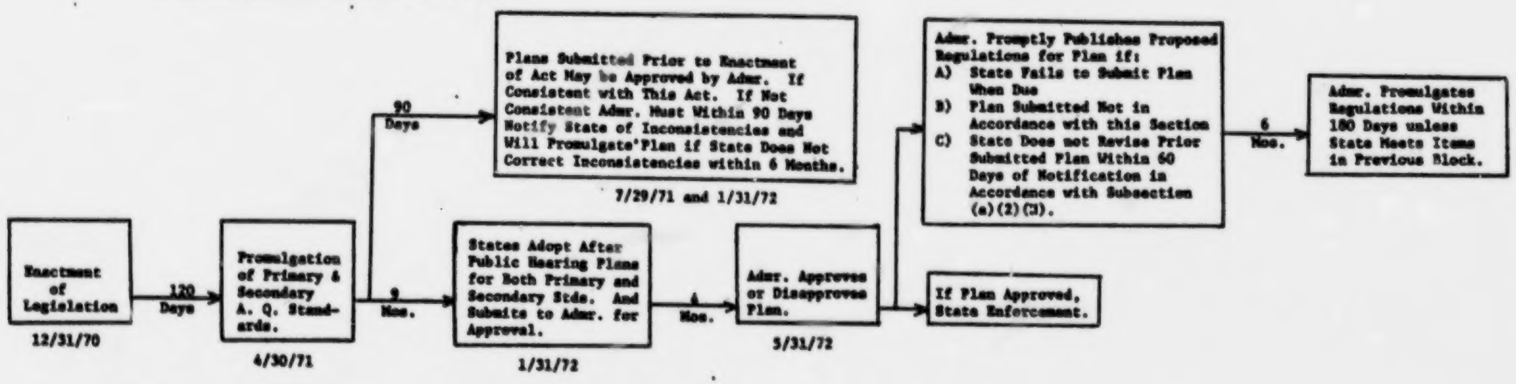

Enactment
of
Legislation
12/31/70
30
Days
Any
Time
Admr. Publish Prop. Reg. on Nat. Primary A. Q. Stds. and Nat. Secondary A. Q. Stds. for Pollutants for which Criteria have been issued prior to Enactment.
1/30/71
Criteria Documents on Other Pollutants Issued From Time to Time Along with Proposed A. Q. Stds.
90
Days
Admr. Promulgates both Types of Stds. After Considering Written Comments.
4/30/71

NOTE: Primary Stds. Based on Health Considering Margin of Safety.

Secondary Stds. Based on Public Welfare.

SECTION 110 - TIME SCHEDULE FOR IMPLEMENTATION PLANS

(CLEAN AIR AMENDMENTS OF 1970 - PL 91-604)

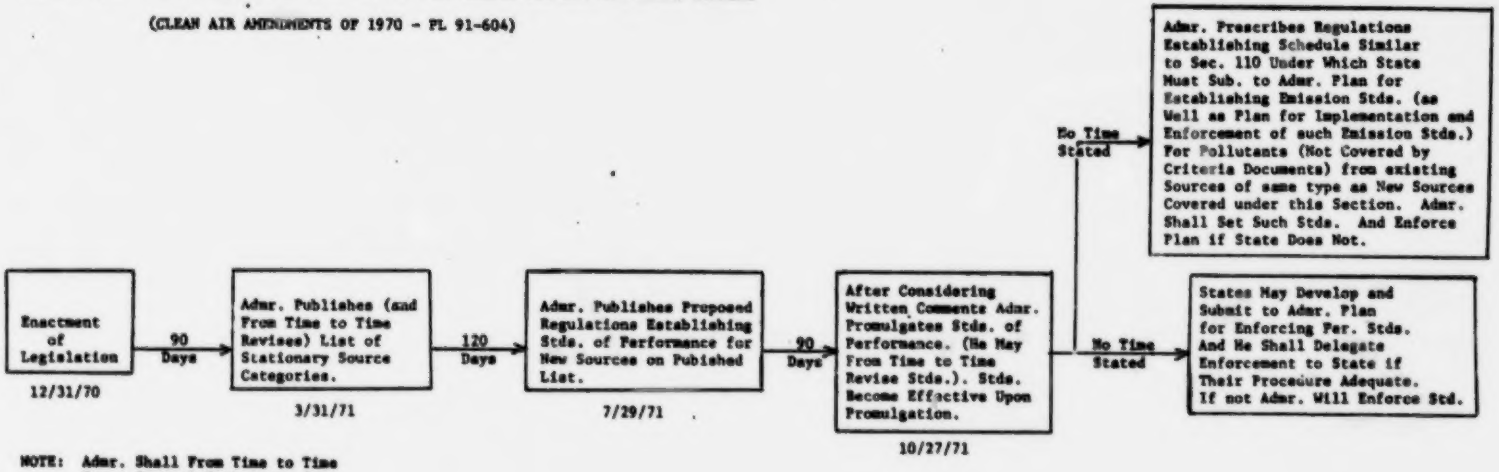

Enactment of Legislation
12/31/70
120 Days
Promulgation of Primary & Secondary A. Q. Standards.
4/30/71
90 Days
Plans Submitted Prior to Enactment of Act May be Approved by Admr. If Consistent with This Act. If Not Consistent Admr. Must Within 90 Days Notify State of Inconsistencies and Will Promulgate Plan if State Does Not Correct Inconsistencies within 6 Months.
7/29/71 and 1/31/72
9 Mos.
States Adopt After Public Hearing Plans for Both Primary and Secondary Stds. And Submits to Admr. for Approval.
1/31/72
4 Mos.
Admr. Approves or Disapproves Plan.
5/31/72
Admr. Promptly Publishes Proposed Regulations for Plan if:
A) State Fails to Submit Plan When Due
B) Plan Submitted Not in Accordance with this Section
C) State Does not Revise Prior Submitted Plan Within 60 Days of Notification in Accordance with Subsection (a)(2)(3).
If Plan Approved, State Enforcement.
6 Mos.
Admr. Promulgates Regulations Within 180 Days unless State Meets Items in Previous Block.

NOTE: Primary Stds. Must be Achieved Within 3 Years, Secondary Stds. By a Reasonable Time Later. Admr. May Extend Date for Achieving Primary Stds. for Not More Than 2 Years.

Admr. May Extend Date for Sub. of Plan for Achieving Secondary Standard not more than 18 Months (See Sec. 110(f)(1) For another Type of Extension the Admr. May Authorize for Certain Stationary or Mobile Sources.)

SECTION 111 - TIME SCHEDULE FOR STANDARDS OF PERFORMANCE FOR NEW STATIONARY SOURCES

(CLEAN AIR AMENDMENTS OF 1970 - PL 91-604)

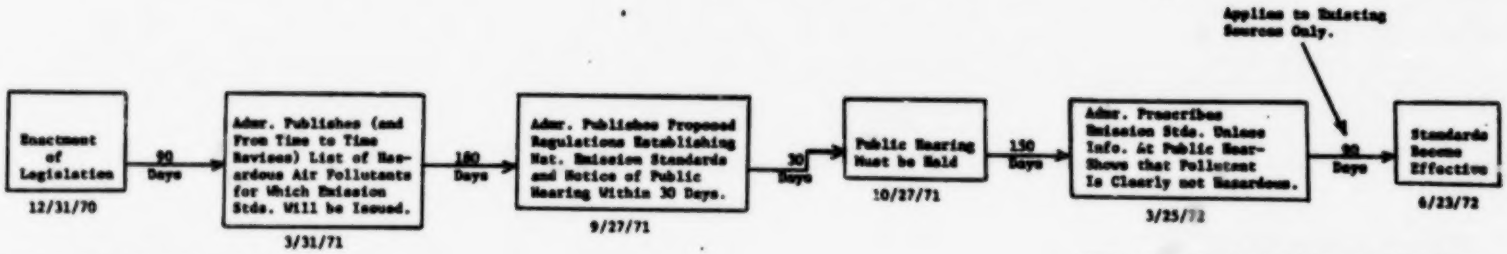

Enactment of Legislation
12/31/70
90 Days
Adnr. Publishes (and From Time to Time Revises) List of Stationary Source Categories.
3/31/71
120 Days
Admr. Publishes Proposed Regulations Establishing Stds. of Performance for New Sources on Pubished List.
7/29/71
90 Days
After Considering Written Comments Admr. Promulgates Stds. of Performance. (He May From Time to Time Revise Stds.). Stds. Become Effective Upon Promulgation.
10/27/71
No Time Stated
Admr. Prescribes Regulations Establishing Schedule Similar to Sec. 110 Under Which State Must Sub. to Admr. Plan for Establishing Emission Stds. (as Well as Plan for Implementation and Enforcement of such Emission Stds.) For Pollutants (Not Covered by Criteria Documents) from existing Sources of same type as New Sources Covered under this Section. Admr. Shall Set Such Stds. And Enforce Plan if State Does Not.
No Time Stated
States May Develop and Submit to Admr. Plan for Enforcing Per. Stds. And He Shall Delegate Enforcement to State if Their Procedure Adequate. If not Admr. Will Enforce Std.

NOTE: Admr. Shall From Time to Time Issue Control Techniques for Categories of New Sources and Pollutants Subject to This Section.

SECTION 112 - TIME SCHEDULE FOR NATIONAL EMISSION STANDARDS FOR HAZARDOUS AIR POLLUTANTS

(CLEAN AIR AMENDMENTS OF 1970 - PL 91-604)

NOTE: States May Submit Plan for Implementing and Enforcement of Std. and Admr. Shall Delegate Such if Adequate. If not Admr. Will Enforce.

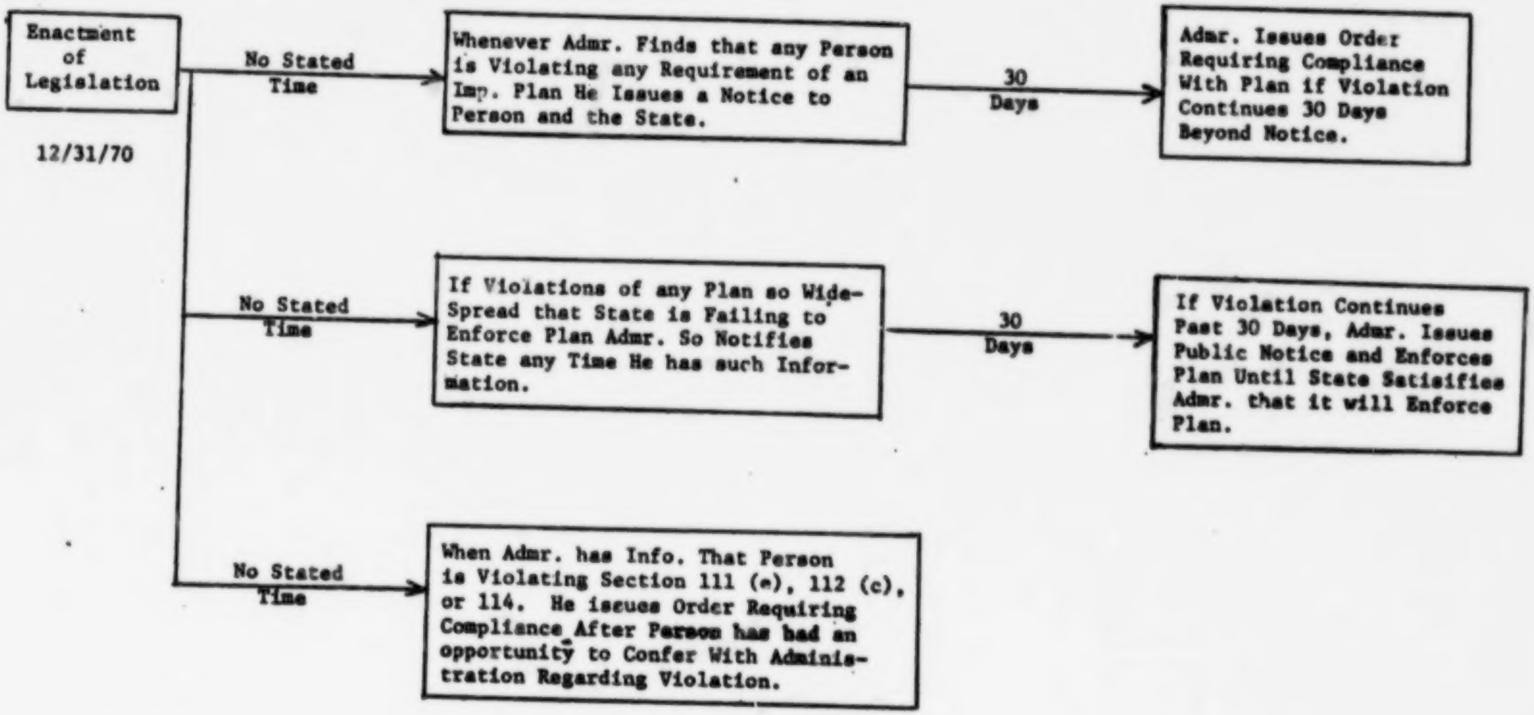

Enactment of Legislation
12/31/70
90 Days
Admr. Publishes (and From Time to Time Revises) List of Hazardous Air Pollutants for Which Emission Stds. Will be Issued.
3/31/71
180 Days
Admr. Publishes Proposed Regulations Establishing Nat. Emission Standards and Notice of Public Hearing Within 30 Days.
9/27/71
30 Days
Public Hearing Must be Held
10/27/71
150 Days
Admr. Prescribes Emission Stds. Unless Info. At Public Hear- Shows that Pollutant Is Clearly not Hazardous.
3/25/72
Applies to Existing Sources Only.
90 Days
Standards Become Effective
6/23/72

NOTE: Admr. Shall Issue from Time to Time Control Techniques for Air Pollutants Under this Section.

NOTE: Admr. May Grant Waiver up to 2 Years if Necessary for Source to Install Controls and Source Will Take Steps to Insure Health of Persons Will be Protected from Imminent Endangerment.

SECTION 113 - TIME SCHEDULE FOR FEDERAL ENFORCEMENT

(CLEAN AIR AMENDMENTS OF 1970 - PL 91-604)



Whenever Admr. Finds that any Person is Violating any Requirement of an Imp. Plan He Issues a Notice to Person and the State.

Admr. Issues Order Requiring Compliance With Plan if Violation Continues 30 Days Beyond Notice.

If Violations of any Plan so Wide-Spread that State is Failing to Enforce Plan Admr. So Notifies State any Time He has such Information.

If Violation Continues Past 30 Days, Admr. Issues Public Notice and Enforces Plan Until State Satisifies Admr. that it will Enforce Plan.

When Admr. has Info. That Person is Violating Section 111 (e), 112 (c), or 114. He issues Order Requiring Compliance After Person has had an opportunity to Confer With Administration Regarding Violation.

preservation, product improvement in addition to storage, handling, packaging and shipping.

The principal air pollutant emission from the food and agricultural processing industry is particulate matter although other pollutants are found in certain particular types of processes. The other pollutants which occur are principally odors (such as trimethylamines and hydrogen sulfides), nitrogen oxides, aldehydes, organic acids, hydrocarbons, carbon monoxides, and fluorides. Although we have essentially no information on trace metal air pollutants from this industry it is probable that such emissions do occur in certain segments of the industry. One should be cognizant of potential pollutants such as biological aerosols and the arsenical and mercurial based pesticides. The latter are often used as defoliants to aid in mechanical cotton picking operations.

The Air Pollution Control Office has not in the past conducted detailed studies of the food processing industry although at the present time we have planned under contract a comprehensive systems study of the food and grain industry.

The Air Pollution Control Office of EPA currently has in the process of publication a comprehensive document entitled Air Pollutant Emission Factors(1). An Emission Factor is defined as "the statistical average of the rate at which a pollutant is released to the atmosphere as a result of some industrial activity divided by the level of that activity." For example, if it is determined that 26,000 tons of carbon monoxide is released to the atmosphere during the production of 260,000 tons of ammonia, the carbon monoxide emission factor for ammonia production would be 200 pounds of carbon monoxide released per ton of ammonia produced. Therefore, it is seen that the emission factor relates the quantity of pollutant emitted to some indication such as production capacity, quantity of fuel burned, etc.

Emission factors are determined and estimated by a whole spectrum of techniques. These include detailed source testing involving many measurements related to a variety of process variables, single measurements not clearly defined as to their relationships to process operating conditions, process material balances and engineering appraisals of a given process. One must be cautious in applying emission factors. In general, emission factors are not precise indicators of emissions from a given source but are extremely useful when intelligently applied in conducting source inventories as part of local, community, or nationwide air pollution studies.

The Air Pollutant Emission Factor document mentioned above will present general information, emissions and control, and emission factors for some ten major industrial categories encompassing some 85 industrial processes. With respect to the food and agricultural industry category the following processes are covered: Alfalfa Dehydrating, Coffee Roasting, Cotton Ginning, Feed and Grain Mills and Elevators, Fermentation, Fish Processing, Meat Smokehouses, Nitrate Fertilizers, Phosphate Fertilizers, Starch Manufacturing, and Sugar Cane Processing. Presented below is a summary of the air pollution aspects of the food and agiculture industry. Information on nitrate and phosphate fertilizers are not given in this paper.

The principal air pollutant emissions from the above mentioned processes are described in the following sections.

Alfalfa Dehydrating. An alfalfa dehydrating plant produces an animal feed from alfalfa. The dehydration and grinding of alfalfa to produce alfalfa meal is a dusty operation most commonly carried out in rural areas.

Wet, chopped alfalfa is fed into a direct-fired rotary drier. The dried alfalfa particles are conveyed to a primary cyclone, where heavy trash is removed. A second cyclone discharges material to the grinding equipment, which is usually a hammer mill. The ground material is collected in an air-meal separator and either conveyed directly to bagging or storage, or blended with other ingredients.

Sources of dust emissions are the primary cyclone, grinders and air-meal separator. Overall dust losses have been reported as high as 7 percent but average losses are around 3 percent by weight of the meal produced. The use of a baghouse as a secondary collection system can greatly reduce emissions. Emission factors for alfalfa dehydrating are presented in Table 1.

TABLE 1 PARTICULATE EMISSION FACTORS FOR ALFALFA DEHYDRATION

Particulate Emissions	lb/Ton of Meal Produced
Uncontrolled	60
Baghouse Collector	3

Coffee Roasting. Coffee, which is imported in the form of green beans, must be cleaned, blended, roasted and packaged before being sold. In a typical coffee roasting operation, the green coffee beans are freed of dust and chaff by dropping the beans in a current of air. The cleaned beans are then sent to a batch or continuous roaster. During the roasting, moisture is driven off, the beans swell, and chemical changes take place that give the roasted beans their typical color and aroma. When the roasting has reached a certain color the beans are quenched, cooled, and stoned.

Dust, chaff, coffee bean oils (as mists), smoke, and odors are the principal air contaminants emitted from coffee processing. The major source of particulate emissions and practically the only source of aldehydes, nitrogen oxides and organic acids is the roasting process. In a direct-fired roaster gases are vented without recirculation through the flame. However, in the -fired roaster, a portion of the roaster gases are recirculated and particulate emissions are reduced. Essentially, complete removal of both smoke and odors from the roasters can be obtained with a properly designed afterburner.

Particulate emissions also occur from the stoner and cooler. In the stoner contaminating materials heavier than the roasted beans are separated from the beans by an air stream. In the cooler, quenching the hot roasted beans with water causes emissions of large quantities of steam and some particulate matter. Table 2 summarizes the emissions from the various operations involved in coffee processing.

TABLE 2 UNCONTROLLED EMISSION FACTORS FOR ROASTING PROCESSES

(pounds per ton of green beans)

Type Process	Pollutant			
	Particulates	NO_x	Aldehydes	Organic Acids
Roaster				
Direct-Fired	7.6	0.1	0.2	0.9
Indirect-Fired	4.2	0.1	0.2	0.9
Stoner and Cooler[a]	1.4	--	--	--
Instant Coffee Spray Dryer	1.4[b]	--	--	--

a - If cyclone is used emissions can be reduced by 70 percent.
b - Cyclone plus wet scrubber always used and thus this represents controlled factor.

Cotton Ginning. The primary function of a cotton gin is to take raw seed cotton and separate the seed and the lint. A large amount of trash is found in the seed cotton which must be removed. The problem of collecting and disposing of gin trash falls into two main areas. The first consists of collecting the coarse heavier trash such as burs, sticks, stems, leaves, sand, and dirt. The second problem area is that of collecting the finer dust, small leaf particles and fly lint that are discharged from the lint after the fibers are removed from the seed. From one ton of seed cotton approximately one 500 pound bale of cotton can be made.

The major sources of particulates from cotton ginning include the unloading fan, the cleaner and the stick and bur machine. From the cleaner and stick and bur machine a large percentage of the particles settle out in the plant. Thus an attempt has been made in Table 3 to present emission factors which take this into consideration. Where cyclone collectors are used emissions have been reported to be about 90 percent less.

Feed and Grain Mills and Elevators. Grain elevators are primarily transfer and storage units and are classified as either the smaller more numerous country elevators or the larger terminal elevators. At grain elevator locations the following operations can occur: receiving, transfer and storage, cleaning, drying, and milling or grinding. Many of the large terminal elevators also process grain at the same location. The grain processes may include wet and dry milling (cereals), flour milling,

TABLE 3 UNCONTROLLED EMISSIONS FROM COTTON GINNING OPERATIONS

Process	Estimated Total Particulates	Atmospheric Emission Settled Out 100	(lbs/bale cotton)[a] Estimated Emission Factor
Unloading Fan	15	0	15
Cleaner	10	70	3
Stick and Bur Machine	6	95	0.3
TOTAL	31	--	18

a - One bale equals 500 pounds

oil seed crushing and distilling. Feed manufacturing involves the receiving, conditioning (drying, sizing, cleaning), blending and pelleting of grains and their subsequent bagging or bulk loading.

Emission from feed and grain operations may be separated into those occurring at elevators, and those occurring at grain processing operations or feed manufacturing operations. Emission factors for these operations are presented in Table 4. Since dust collection systems are generally applied to most phases of these operations to reduce product and component losses, the selection of the final emission factor should take into consideration the overall efficiency of these control systems.

The emissions from grain elevator operations are dependent on the types of grain, the moisture content of the grain (usually 10-30 percent), amount of foreign material in the grain (usually 5 percent or less), the degree of enclosure at loading and unloading areas, the type of cleaning and conveying, and the amount and type of control used.

Factors affecting emissions from feed manufacturing operations include the type and amount of grain handled, the degree of drying, the amount of liquid blended into the feed, the type of handling (conveyor or pneumatic), and the degree of control.

Fermentation. For the purpose of this paper only the fermentation industries associated with food will be considered. This includes the production of beer, whiskey and wine.

The manufacturing process for each of these is similar. The four main brewing production stages and their respective sub-stages are: (1) Brewhouse operations, which includes a) malting of the barley, b) addition of adjuncts (corn, grits and rice) to barley mash, c) conversion of starch in barley and adjuncts to maltose sugar by enzymatic processes, d) separation of wort from grain by straining, and e) hopping and boiling of the wort; (2) fermentation, which includes a) cooling of the wort, b) additional yeast cultures, c) fermentation for 7 to 10 days, d) removal of settled yeast, and e) filtration and carbonation; (3) aging, which

TABLE 4 UNCONTROLLED PARTICULATE EMISSION FACTORS FROM GRAIN HANDLING AND PROCESSING

(pounds per ton of grain processed)

Type Source	Emissions
Terminal Elevators	
Shipping or Receiving	1
Transferring, Conveying, etc.	2
Screening and Cleaning	5
Drying	6
Country Elevators	
Shipping or Receiving	5
Transferring, Conveying, etc.	3
Screening and Cleaning	8
Drying	7
Grain Processing	
Alfalfa Meal Milling	0.2
Corn Meal	5
Soybean Processing	7
Barley or Wheat Cleaner	0.2[a]
Milo Cleaner	0.4[a]
Barley Flour Milling	3[a]
Feed Manufacturing	
Barley	3[a]

[a] - At cyclone exit (only non-ether soluble particulates)

lasts from 1 to 2 months under refrigeration and (4) packaging, which includes a) bottling-pasteurization and b) racking draft beer.

The major differences between beer production and whiskey production are the purification and distillation necessary to obtain distilled liquors and the longer period of aging. The primary difference between wine making and beer making is that grapes are used as the initial raw material rather than grains.

Emissions from fermentation processes are nearly all gases and primarily consist of carbon dioxide, hydrogen, oxygen, and water vapor, none of which presents an air pollution problem. However, emissions of particulates can occur in the handling of the grain in the manufacture of beer and whiskey. Gaseous hydrocarbons are also emitted from the whiskey aging warehouses. No significant emissions have been reported for the production of wine. Emission factors for the various operations associated with beer, wine and whiskey production are shown in Table 5.

TABLE 5 EMISSION FACTORS FOR FERMENTATION PROCESSES

Type Product	Particulates	Hydrocarbons
Beer (lb/ton of grain processed)		
Grain Handling[a]	3	--
Drying Spent Grain, etc.[a]	5	NA
Whiskey (lbs/ton of grain processed)		
Grain Handling[a]	3	--
Drying Spent Grains, etc.[a]	5	NA
Aging (lbs/year/barrel of whiskey stored)	--	10
Wine	Neg.[b]	Neg.[b]

a - Based on section of grain processing.

b - No significant emissions.

NA - No emission factor available, but emissions do occur.

Fish Processing. The canning, dehydration, smoking of fish, and the manufacture of fish meal and fish oil are the important segments of fish processing. There are two types of fish canning operations--the "wet-fish" method in which the trimmed fish are cooked directly in the can and the "pre-cooked" process in which the whole fish is cooked and then hand-sorted before canning.

A large fraction of the fish received in a cannery is processed into by-products. The most important of these by-products is fish meal. In the manufacture of fish meal fish scrap from the canning lines is charged to continuous live-stream cookers. After the material leaves the cooker it is pressed to remove oil and water. The press cake is broken up, usually in a hammer mill, and dried in a direct-fired rotary drier or in a steam-tube rotary drier.

The biggest problem from fish processing is odor emissions. The principal odorous gases generated during the cooking process of fish meal manufacturing are hydrogen sulfide and trimethylamine. Some of the methods used to control odors include activated carbon **adsorbers**, scrubbing with some oxidizing solution and incineration. The only significant sources of dust emissions in fish processing are the driers and grinders used to handle dried fish meal. Emission factors for fish meal manufacturing are shown in Table 6.

TABLE 6 EMISSION FACTORS FOR FISH MEAL PROCESSING

Emission Source	Particulates	Trimethylamine $(CH_3)_3N$	Hydrogen Sulfide H_2S
Coolers (lbs/ton fish meal produced)			
Fresh Fish	--	0.3	0.01
Stale Fish	--	3.5	0.2
Driers (lbs/ton fish scrap)	0.1	--	--

Meat Smokehouses. Smoking is a diffusion process in which food products are exposed to an atmosphere of hardwood smoke, causing various organic compounds to be absorbed by the food. Smoke is produced commerically in the United States by three major methods: (1) burning dampened sawdust (20-40 percent moisture), (2) burning dry (5-9 percent moisture) sawdust continuously, and (3) by friction. Burning dampened sawdust and kiln-dried sawdust are the most widely used methods. Most large, modern, production meat smokehouses are the recirculating type, in which smoke is circulated at reasonably high temperatures throughout the smokehouses.

The emissions from smokehouses are generated from the burning hardwood, rather than from the cooked product itself. Based on approximately 110 pounds of meat smoked per pound of wood burned, emission factors have been derived for meat smoking. These factors are presented in Table 7.

Emissions from meat smoking are dependent on several factors, including the type of wood, type of smoke-generator, moisture content of the wood, air supply, and amount of smoke recirculated. Both low voltage electrostatic precipitators and direct-fired afterburners may be used to reduce particulate and organic emissions. Thus controlled emission factors have also been shown in Table 7.

TABLE 7 EMISSION FACTORS FOR MEAT SMOKING

(pounds per ton of meat)[a]

Pollutant	Uncontrolled	Controlled[b]
Particulates	0.3	0.1
Carbon Monoxide	0.6	Neg.[c]
Hydrocarbons (CH_4)	0.07	Neg.[c]
Aldehydes (HCHO)	0.08	0.05
Organic Acids (Acetic)	0.2	0.1

a - Based on 110 pounds of meat smoked per pound of wood burned.

b - Controls consist of a wet collector and low voltage precipitator in series, or direct-fired afterburner.

c - With afterburner

Starch Manufacturing. The basic raw material in the manufacture of starch is dent corn which contains starch. The starch in the corn is separated from the other components by "wet milling."

The shelled grain is prepared for milling in cleaners which remove both the light chaff and any heavier foreign material. The cleaned corn is then softened by soaking (steeping) it in warm water acidified with sulfur dioxide. The softened corn goes through attrition mills, which tear the kernels apart freeing the germ and loosening the hull. The remaining mixture of starch, gluten and hulls is finely ground and the coarser fiber particles are removed by screening. The mixture of starch and gluten is separated by centrifuges. After separation from the gluten, the starch is filtered and washed. At this point it may be dried and packaged for market.

The manufacture of starch from corn can result in significant dust emissions. The various cleaning, grinding and screening operations are the major sources of dust emissions. Table 8 presents emission factors for starch manufacturing.

TABLE 8 EMISSION FACTORS FOR STARCH MANUFACTURING

(pounds per ton of starch produced)

Overall Emissions	Particulates
Uncontrolled	8
Controlled[a]	0.02

a - Based on centrifugal gas scrubber

Sugar Cane Processing. The processing of sugar cane starts with the harvesting of the crops, either by hand or by mechanical means. If mechanical harvesting is used much of the unwanted foliage is left and it thus is standard practice to burn the cane before mechanical harvesting to remove the greater part of the foliage.

Following harvesting, the cane goes through a series of processes to be converted to the final sugar product. It is washed to remove larger amounts of dirt and trash, crushed and shredded to reduce the size of the stalks and then the juice is extracted by two methods, milling or diffusion. In milling the cane is pressed between heavy rollers to press out the juice and in diffusion the sugar is leached out by water and thin juices. The raw sugar then goes through a series of operations including clarification, evaporation and crystallization in order to produce the final product.

Most mills operate without supplement fuel because of the sufficient bagasse (the fibrous residue of the extracted cane) that can be burned as fuel.

The largest sources of emissions from sugar cane processing are the open field burning in the harvesting of the crop and the burning of bagasse as fuel. In the various processes including crushing, evaporation and crystallization some particulates are emitted but in relatively small quantities. Emission factors for sugar cane processing are shown in Table 9.

TABLE 9 EMISSION FACTORS FOR SUGAR CANE PROCESSING

Type Process	Particulate	Carbon Monoxide	Hydro-carbons	Nitrogen Oxides
Field Burning[a,b] (lbs/acre burned)	225	1,500	300	30
Bagasse Burning (lbs/ton bagasse)	22	--	--	--

a - Based on emission factors for open burning of agricultural waste.

b - There are approximately 4 tons/acre of unwanted foliage on the cane and 11 tons/acre of grass and weed all of which is combustible.

REFERENCES

1. McGraw, M. J., Air Pollutant Emission Factors, United States, DHEW, PHS, 1970.

ACTIVITIES IN MANAGING SOLID WASTES

by

Jack DeMarco*

SCOPE OF THE PROBLEM

Our American way of life that has given us the highest standard of living in the world has not been without its cost. Now that our gross national product has exceeded the trillion dollar level, we are discovering that increased goods and services come to us at the expense of our environment. Attempting to assess the blame for the current state of our environment is futile. Our efforts must be more efficiently expended in ensuring that further degradation of the environment does not take place.

It is encouraging to note that this is indeed happening. Public concern for protecting environmental quality is growing. We all have just cause to be concerned. Solid waste management practices throughout the nation have in general been deplorable. An estimated 3.5 billion tons of solid waste are generated each year from household, commercial, and municipal, industrial, mining and agricultural activities across the Nation. Over 2 billion tons of this total are related to industrial, agricultural, and animal wastes. Annually, over a million abandoned cars are scattered across the Nation, and a good portion of the 48 billion cans and 26 billion bottles thrown away each year also decorate our landscape in an unsightly manner.

Unfortunately, the wastes that get into our solid waste handling systems are not managed in a way that will prevent degradation of environmental quality. The results of our first national survey of community solid waste practices revealed that the most common practice of disposal for our community solid waste is the open burning dump (1). Over 95 percent of the estimated 15,000 land disposal sites were judged unsatisfactory as they related to potential air, water pollution, and vector control problems. Incinerators did not fare much better. We found that over 75 percent of the estimated 300 incinerators located across the Nation were judged unacceptable in terms of the air and water pollution problems that occur from their operation. In many cases the objective of reducing the solid waste volume was conducted so inefficiently that large amounts of residue were left to be disposed of. An estimated $4.5 billion per year have been expended by municipalities, private solid waste management firms, individuals, or

---

* Deputy Director, Division of Technical Operations, Solid Waste Management Office, U.S. Environmental Protection Agency, Cincinnati, Ohio.

Preceding page blank

private industrial organizations on solid waste collection and disposal. Although this figure may seem impressive, it has not been enough to provide satisfactory management systems for the waste of this Nation. We must all do more to stop the degradation and then ultimately restore the quality of our environment.

THE FEDERAL ROLE

Until October 20, 1965, there was practically no federal involvement with solid waste management. On that date, Congress, in passing the Solid Waste Disposal Act, outlined responsibilities for the Federal Government that would speed the growth of solid waste technology (2). On October 26, 1970, Congress amended the Solid Waste Disposal Act to further strengthen and expand the federal role (3). The original act and its amendments state that the federal role shall be:

1. To promote the demonstration, construction, and application of solid waste management and resource recovery systems which preserve and enhance the quality of air, water, and land resources.

2. To provide technical and financial assistance to States and local government and interstate agencies in the planning and development of resource recovery and solid waste disposal programs.

3. To promote a national research and development program for improved management techniques, more effective organizational arrangements, and new and improved methods of collection, separation, recovery, and recycling of solid wastes, and the environmentally safe disposal of nonrecoverable residues.

4. To provide for the promulgation of guidelines for solid waste collection, transport, separation, recovery, and disposal systems.

5. To provide for training grants in occupations involving the design, operation, and maintenance of solid waste disposal systems. The Solid Waste Management Office, of the newly formed U.S. Environmental Protection Agency, has many activities underway designed to fulfill the federal role of helping to solve the national solid waste management problem.

Demonstrations

Our program has funded over 125 demonstration grant projects to date (4). Some are designed to show the feasibility of new and improved solid waste management technology. These grants allow for full-scale demonstration of methods, facilities, and equipment under actual operating conditions. Other demonstration grants have been awarded to demonstrate that sanitary and economic solid waste operations can be accomplished by regional authorities.

There are completed or currently active demonstration grants for all phases of solid waste management. Some of these projects that deal directly with agricultural and animal waste problems may be of particular interest to you. The Metropolitan Sanitary District of Greater Chicago and the University of Illinois are demonstrating what agricultural benefits and environmental changes result from using digested sewage sludge on field crops. The objective of the project is to determine the practicality of disposing of digested sewage solids on land. Primary consideration is given to investigating factors relevant to surface and groundwater contamination; soil pollution by heavy metals, grease, and organic compounds inherent in sewage sludge; method, frequency, rates, and times for safe application on sandy soil. Preliminary results indicate that the uptake of zinc in soy beans, reed canary grass, and grain sorghum plants appeared to increase when sludge was applied. Additionally, the yield from corn and kenaf plots showed a favorable increase in yield as the sludge application was increased. Continuing laboratory and greenhouse experiments will obtain information concerning the fertility value of digested sludge, the amounts of supplemental potassium fertilization required for high yields of corn and soy beans, the accumulation of heavy elements in the soil, and methods of reducing nitrate accumulations in soil drainage waters. These investigations should provide a sounder basis for the ultimate disposal of millions of tons of digested sewage sludge and animal manure.

Another demonstration project is designed to improve present methods of land disposal of waste sea clamshells. The current disposal methods have resulted in public health hazards, nuisances, and associated social and political problems that plague coastal communities. The objective of this project is to demonstrate a practical use of waste sea clamshells as oyster cultch material. The oyster planting areas will be scientifically sampled and the shells examined to determine the effect of volume and area of planting and of shell size on intensity of spat-setting and survival. Data to determine any possible ill effects on the environment will be correlated with spat-setting determinations to evaluate overall conditions in these oyster setting areas.

We have two demonstration projects underway on dairy manure management methods. Both studies involve evaluation of existing and proposed methods for collecting dairy manures. In Pullman, Washington, the objectives to be demonstrated are the feasibility of a properly constructed and operated anerobic lagoon for low-cost storage of dairy manure during seasons unfavorable for land disposal; the advantages of properly scheduled applications of dairy manure to farm lands and areas having seasonally high rainfall and land runoff problems; and the feasibility of employing lagoon treatment for dairies not having sufficient land for solids disposal.

In a study at Cerritos, California and through a subsequent demonstration grant with Los Angeles County, the relative economic and aesthetic advantages of a water transport system versus a dry system for collection and disposal of manure will be compared. The problems related to raising and feeding large numbers of dairy cattle on concentrated feedlots and corrals located near residential developments will also be studied. Dairy manure composting will be the principal disposal aspect investigated. The basic data will hopefully aid in establishing the required size of composting units needed for a given number of cows, the frequency of turning needed to produce a suitable product in minimum time, and the aesthetic and vector problems present, if any. Through the grant, an attempt will be made to evaluate the attitudes of people living near dairies and also to assess cause of complaints about the dairies from sanitarians, city managers, and other officials.

All this is only a small sampling of the many demonstration projects underway. These projects were selected because of some related interests they have to this particular symposium. Still other projects deal with milling, grinding, baling, bagging, and crushing of refuse to obtain volume reduction or to improve salvage; incineration; more effective use of land disposal methods; composting, rail and pipeline transportation of waste, and above-ground fills.

One of our particularly promising demonstration projects is related to the use of solid waste as a supplementary fuel in pulverized, coal-fired boiler furnces for generating steam for electric power. The project may result in a solid waste management technique that will provide: economic disposal of urban-area refuse, a low-sulfur fuel to assist in reducing the air pollution burden from utilities, and utilization of waste material as a resource with the consequent conservation of our reserves of coal as a natural resource.

Another promising project is being conducted that will include fluid mechanical separation of solid waste, fluid-bed oxidation of combustibles, and sanitary landfilling of inerts. The project includes potential resource recovery aspects for paper fibers, ferrous and nonferrous metals, and glass.

Our many projects cover the problems faced by small rural communities as well as those faced by thelarge metropolitan complexes of our Nation.

Research

Our Division of Research and Development has activities underway in all phases of the solid waste management problems. Our research activities include intramural projects and projects supported through contracts and grants (5,6). Three distinct areas that provide a broad framework for many of our present research activities are: (1) public health effects of solid waste in various solid waste management systems; (2) utilization of waste materials; and (3) improved process control activities.

Public Health Effects. This research involves investigation of pathogens associated with incineration, composting, landfill, and other disposal methods. It also involves investigation of chemical toxicants and potential occupational hazards associated with solid waste management. One of our initial intramural projects was a study of pathogen survival during the course of incineration (7). It has been generally assumed that pathogens are effectively destroyed through the incineration process, but recent in-house studies indicate that these organisms may survive in significant numbers in incinerator residues. Another in-house project was designed to study the hazardous material selenium (8). This naturally occurring substance is concentrated in plants that are the source of cellulose for paper production. Since large amounts of paper are present in solid waste, a study was conducted to assess what the concentrations of selenium in solid waste were at different phases throughout a processing system. Raw solid waste contained between 0.9 and 4.74 micrograms per gram; incinerator residue, 0.003 microgram per gram; the fly-ash quench water, 0.023 mg/l; the incinerator stack gas, 0.23 microgram per cubic meter; and newspaper, 8.6 micrograms per gram. Recommended threshold limits for selenium in air are 0.2 milligram per cubic meter and in drinking water 0.01 mg/l (9). If we are to know whether the components of solid waste are within allowable thresholds, we must continue further investigations of this sort.

Utilization. These activities involve characterizing various types of solid waste, and determining their chemical, physical, and microbiological characteristics so that substances with an intrinsic value can be identified and returned to the useful product cycle. Agricultural wastes, in particular, may have a large potential in this respect. An example of a project directed at utilizing solid waste is one to develop physical, chemical, and microbial systems for converting the cellulose in solid waste into useful material. Preliminary tests have been run with microorganisms and enzymes to determine their relative abilities to degrade cellulose such as paper, rice hulls, and mixed refuse. The use of certain effective fungi results in a product with a 15 percent protein content. In another study, a 2-liter pressure reactor has been found effective in producing glucose from waste cellulose by an acid hydrolysis process.

Activities are underway through a research grant that will attempt to develop microbial protein food from cellulosic solid waste. A pilot plant is being constructed that will initially utilize sugar cane bagasse as a substrate for this conversion process. Another research institution has a grant to pursue the study of chemical transformations of solid waste to products of useful value. To date, their studies indicate that the most promising chemical treatment processes appear to be utilization of waste cellulose by ester and ether formation and hydrogenation of wastes to oil. The transformed wastes may find use as construction materials, containers, laminates, and other useful products.

Process Control. In the area of process control, we are seeking improved and integrated processing systems for storage, collection, transportation as well as ultimate disposal of solid waste. These studies rely heavily on pilot engineering investigations. An example of such activity would be the joint U.S. Public Health Service--Tennessee Valley Authority Composting Plant at Johnson City, Tennessee (10). This facility has been used as a combination research testing and demonstration plant for composting solid waste and sewage sludge. Another type of process control activity is the fluidized-bed investigations being conducted by research grants in West Virginia.

Technical Operations

Our Division of Technical Operations conducts many activities directly related to coping with the national solid waste management problem. These include planning, training, and technical assistance.

Planning. State and interstate planning grants are awarded to assist States in developing comprehensive State solid waste management plans designed to protect the public from pollution, disease, and nuisance; to provide an effective and economic means of managing solid waste; and to recover resources that can be returned to a productive cycle. Through these plans, State agencies can encourage and guide both local and regional efforts. Since the award of the first grant in June 1966, we have awarded grants to 43 states, 5 interstate agencies, the District of Columbia, Puerto Rico, and Guam. Actual progress is not measured by simply awarding grants. More important is the completion and implementation of the comprehensive solid waste plans. We are pleased that 22 State and 3 interstate plans are completed and implementation has begun on many of them. Recent amendments to the Solid Waste Disposal Act have expanded our planning grants to include local government entities.

Training. Training of solid waste management personnel is another area in which there is still a need. Basic training courses in solid waste management have been offered in Cincinnati and at field locations by our personnel. Over 3,500 trainees have attended these short-term (usually 1-week) courses, which have provided the basic orientation for many State agency regulation personnel, university professors, planners, and supervisors and managers of public and private solid waste management systems.

In addition to our in-house training activities, we now have 13 active solid waste training grants at the graduate level (6). Through these training grants and our in-house efforts, we are attempting to fill the need for solid waste management practitioners. The Solid Waste Disposal Act amendments have also expanded the list of eligible participants for solid waste training grants. This expansion should substantially assist our efforts to provide trained personnel at all levels of operation for solid waste management activities.

Technical Assistance. Much of our past effort has been expended in providing technical assistance, and we expect this to continue. Although technical assistance was not defined in the Solid Waste Disposal Act, I believe the simplest definition might be that "technical assistance is the provision of existing technology to solve present problems." At least three basic methods are used to provide technical assistance:

1. Developing and disseminating technical data and information related to the various aspects of solid waste management.

2. Providing guidelines and standards for acceptable solid waste management.

3. Providing technical personnel to conduct studies, surveys, and evaluations that will assist individuals, public agencies, and private organizations in solving their solid waste management problem.

Technical Data. The technical data we supply includes such information as Sanitary Landfill Facts, which draws together general information that can be used by personnel involved with the management of environmental activities who are not technically versed in all aspects of sanitary landfill operation (11).

For the more technically oriented personnel, we can provide data on such matters as the characteristics of solid waste (12) or the physical, chemical, and microbial characteristics of emissions from solid waste processing operations such as incinerators. Other types of technical data have been issued on solid waste management in municipal, commercial, industrial, and recreational activities (14-17).

Additional data are being developed through industrial solid waste contracts. A report on our contract on the status of solid waste management in the food processing industry will be included in the proceedings of this symposium. We also have contracts underway or already completed that will result in technical reports on the polymer, rubber, automotive, auto dismantling, printing and publishing, industrial chemical, drug, and household appliance industries.

Guidelines and Models. Our present guidelines are state-of-the-art documents that delineate the best technical information and methodology currently available for practicing proper solid waste management at various types of facilities. One such document, already completed, is Incinerator Guidelines 1969 (18). A panel of nationally recognized experts assisted us in developing this guideline. The document is intended to aid in the design and operation of incinerators by making known the best methods now available. Another document, now in the final publication stages, deals with the design and operation of sanitary landfill (19). An additional document is on current methodology for closing open dumps (20).

In the next two years, many more such documents will be developed for all phases of solid waste management and resouce recovery systems. Two projects on legislation are now in the final stages of development. One will result in a model State solid waste management act. The other project will result in model local, county and regional ordinances for solid waste management. Activities such as these are intended to provide guides, for use throughout the Nation, for people at all levels of government and private industry interested in the proper management of solid waste.

Study, Survey, and Evaluation Assistance. Another method of providing technical assistance is by having our technical staff directly assist those individuals, agencies, or organizations that request our advice, counsel, and opinion. In fiscal year 1970 we received over 750 such technical assistance requests. To date in this fiscal year, we have received over 400 requests. Many only require a discussion of technical aspects of some process of solid waste management. Others require field site visits, studies, and evaluations by a qualified person or team from the Division of Technical Operations. Technical requests for field studies have included short-term testing of incinerators for all aspects of their environmental impact including the quality of air, water, and residue emissions from the facility, as well as evaluating a facility's efficiency for solid waste reduction and its economic operation. These studies have assisted in evaluating incinerator operations with the purpose in mind of upgrading them so that they can more adequately perform their function of reducing the volume of solid waste while minimizing any insult to the quality of our environment.

CLOSING REMARKS

I have tried to give you a brief cross section of some of the activities of the Federal solid waste management program. I would like to emphasize that a large part of our efforts are devoted to the concept of resource recovery. Many of the projects I've described already embody this concept. More needs to be done. No longer can we afford to permit solid waste materials to be single-use items. They must be returned to the useful product cycle to be used again. I am sure that you in the food processing industry realize as well as I do that you are front runners in applying the concept of resource recovery and utilization. An estimated 70 percent of the process wastes throughout the food processing industry are converted into byproduct use such as animal feed, charcoal, oil, vinegar, alcohol, and fertilizer. The Nation would encourage you to continue your activities along these lines, and we hope to assist you in continuing to find new uses and new methods for taking what was once waste, treating them as out-of-place resources, and then returning them to the productive cycle of our economy.

REFERENCES

1. Black, R. J., A. J. Muhich, A. J. Klee, H. L. Hickman, Jr., and R. D. Vaughan. The national solid wastes survey; and interim report. [Cincinnati], U.S. Department of Health, Education, and Welfare, [1968]. 53 p.

2. The Solid Waste Disposal Act; Title II of Public Law 89-272, 89th Cong., S.306, October 20, 1965. Washington, U.S. Government Printing Office, 1966. 5 p.

3. The Resource Recovery Act; Public Law 91-512, 91st Cong., H.R. 11833, October 26, 1970. [Washington, U.S. Government Printing Office, 1970.] 9 p.

4. Sponagle, C. E. Summaries; solid wastes demonstration grant projects--1969. Public Health Service Publication No. 1821. Washington, U.S. Government Printing Office, 1969. 175 p.

5. Clemons, C. A., and R. J. Black. Summaries of solid wastes program contracts, July 1, 1965--June 30, 1968. Public Health Service Publication No. 1897. Washington, U.S. Government Printing Office, 1969. 46 p. Supplement (insert). July 1, 1968--June 30, 1969. 12 p.

6. Lefke, L. W., comp. Summaries of solid wastes research and training grants--1968. Public Health Service Publication No. 1596. Washington, U.S. Government Printing Office, 1968. 48 p. Reprinted 1970. Supplemental (insert), Jan. 1, 1968--July 1, 1970. 8 p.

7. Peterson, M. L. and F. J. Stutzenberger. Microbiological evaluation of incinerator operations. Applied Microbiology, 18(1): 8-13. July 1969.

8. Johnson, H. Determination of selenium in solid waste. Environmental Science & Technology, 4(10): 850-853, Oct. 1970.

9. American Conference on Governmental Industrial Hygienists. Threshold limit values of airborne contaminants adopted by ACGIH for 1969; and intended changes. Cincinnati, 1969. 28 p.

10. Wiley, J. S., F. E. Gartrell, and H. G. Smith. Concept and design of the joint U.S. Public Health Service--Tennessee Valley Authority Composting Project, Johnson City, Tennessee. [Cincinnati], U.S. Department of Health, Education, and Welfare, 1968. 14 p.

11. Sorg, T. J., and H. L. Hickman, Jr. Sanitary landfill facts. Public Health Service Publication No. 1792. Washington, U.S. Government Printing Office, 1968. 26 p.; 2d ed., 1970. 30 p.

12. Klee, A. J., and D. Carruth. Sample weights in solid waste composition studies. Journal of the Sanitary Engineering Division, Proc. ASCE, 96(SA4): 945-954, Aug. 1970.

13. Achinger, W. C., and L. E. Daniels. An evaluation of seven incinerators. In Proceedings; 1970 National Incinerator Conference, Cincinnati, May 17-20, 1970. New York, American Society of Mechanical Engineers. p. 32-64.

14. Perkins, R. A. Satellite vehicle systems for solid waste collection; evaluation and application. Solid Waste Management Office for release through National Technical Information Service, 1971. (In press.)

15. DeGeare, T. V., Jr., and J. E. Ongerth. An empirical analysis of commercial solid waste generation. (Submitted for publication.)

16. Cummins, R. L., W. T. Dehn, H. T. Hudson, and M. L. Senske. Planning a comprehensive in-plant solid waste survey. [Cincinnati], U.S. Department of Health, Education, and Welfare, 1970. 9 p.

17. Spooner, C. S. Study of recreation solid wastes for the U.S. Department of Agriculture Forest Service. Public Health Service Publication No. 1991. Washington, U.S. Government Printing Office, 1969. 134 p. (In press.)

18. DeMarco, J., D. J. Keller, J. Leckman, and J. L. Newton. Incinerator guidelines--1969. Public Health Service Publication No. 2012. Washington, U.S. Government Printing Office, 1969. 98 p.

19. Brunner, D. R., and D. J. Keller. Sanitary landfill--design and operation. Washington, U.S. Government Printing Office, 1971. (In press.)

20. Closing open dumps. D. R. Brunner, S. J. Hubbard, D. J. Keller, and J. L. Newton. [Washington, U.S. Government Printing Office], 1971. 19 p.

POLLUTION ABATEMENT AND BY-PRODUCT RECOVERY IN THE SHELLFISH INDUSTRY

by

Edwin Lee Johnson and Quintin P. Peniston*

INTRODUCTION

The shellfish industry, herein limited to crustacea species, is of considerable, and rapidly increasing, importance in many world localities. Current domestic landings and imports of shrimp alone in the United States amount to more than one half billion pounds per year. Characteristically, all species possess an exo-skeleton which is not used for food purposes. The yield of edible meat generally amounts to from 17 percent live weight for small shrimp to about 25 percent for larger crab species. The remainder is waste and in many fisheries this is discharged into harbor waters adjacent to the processing facilities.

Food, Chemical & Research Laboratories, Inc. has been active for the past five years in development of processes for separation of shellfish wastes into marketable commodities of greater value than crude shellfish meals. Much of this work has been supported by the U.S. Bureau of Commercial Fisheries. Work is being continued under joint sponsorship by the Environmental Protection Agency and the City of Kodiak, Alaska, Project 11060-FJQ.

Process Description

The process as originally conceived involves total recovery of waste constituents to produce calcium chloride brines, protein and chitin as by-products. It would consist of two counter-current extraction treatments. The first would employ waste hydrochloric acid to decompose calcium carbonate and produce calcium chloride brine. By suitable control of flow and recycling, brine concentrations of the order of 20 percent can be attained.

The residue, consisting of protein and chitin, is extracted with dilute sodium hydroxide solution to dissolve and remove all of the protein in the waste as a sodium proteinate solution. This extraction would also be conducted as a counter-current operation in order to obtain high protein concentration in the extract.

Protein is recovered from the extracts by neutralization with hydrochloric acid to the iso-electric point of the protein which occurs at a pH level of about 4.0. The precipitated protein is separated from the supernate by filtration or centrifugation, washed to reduce the salt content and dried.

---

*Food, Chemical & Research Laboratories, Inc., Seattle, Washington

Residue from the sodium hydroxide extraction is essentially pure chitin. It can be washed and dried and marketed as chitin or can be converted directly to soluble derivatives such as chitosan. The isolation of chitin by demineralization of crustacea shells with acid and removal of protein with alkali has been known and practiced for many years. To our knowledge however, recoveries of calcium chloride brine and protein have not heretofore been considered.

In the final report under Contract No. BCF 14-17-0007-960 it was concluded that the process as described above was both practically and economically feasible in locations where waste hydrochloric acid was available at low cost and a market existed for calcium chloride brines. It was further concluded that the process without modification probably would not be economic at Kodiak, due to the high costs for delivery of hydrochloric acid to that area.

Revised Process for Kodiak, Alaska

In the interim period between completion of Contract BCF 14-17-0007-960 and execution of Contract No. BCF 14-17-0007-984 it was determined that reversal of the order of demineralization and protein removal was practical and that a revised process involving only protein extraction from the waste shell could be economic at Kodiak. The residue, consisting of a matrix of calcium carbonate and chitin, would have potential Alaska markets as a fertilizer and soil liming agent or could be exported to a Puget Sound location for demineralization. It has a very real advantage over raw shell in being bacteriologically stable by virtue of protein removal and can be shipped in bulk in a moist condition without putrefaction.

In consideration of the above findings it was thought desirable to study protein isolation and its characteristics using other shellfish species, namely shrimp, Dungeness crab and Tanner crab, as well as King crab on which most of the data to that date had been obtained. Trends at Kodiak indicate rising levels of shrimp production with decreasing production of King crab. Dungeness and Tanner crab may also become larger factors in the total waste load.

Plan of Work for Present Contract

Accordingly, a request was made for continued support to study the modified process as it might apply to Kodiak with particular emphasis on isolation, recovery and characterization of protein from all species of interest. This resulted in the present contract which was later amended to include consideration of fish wastes such as those from processing salmon, halibut and herring.

Results of studies under this contract have been presented in progress reports during the contract period. In the present report above results are collected and summarized under the following subjects.

1. Waste Composition and Behavior in the Alkali Extraction Process.

2. Factors Determining Rate of Protein Extraction.

3. Recoverability of Protein by Isoelectric Precipitation.

4. Factors Influencing Protein Quality.

5. Possible Utility of Products.

6. Processing Equipment Indications.

7. Pollution Abatement.

8. Economic Considerations.

DISCUSSION

1. Waste Composition and Behavior in the Alkali Extraction Process

While shellfish waste from all crustacea species are primarily mixtures of calcium carbonate, protein and chitin, there is considerable variation between species as to the relative amounts of these substances and also as to minor components such as lipids, pigments, phosphates, etc. Further, butchering wastes from crab processing will contain visceral materials as well as shell. In addition, a waste treatment plant at Kodiak, to offer complete abatement of all primary pollution from fishery operations, should provide facilities for handling fishery wastes such as salmon offal, halibut trimmings and herring wastes. These will contain flesh, blood and collagen type proteins, fats and bone as primary constituents.

Differences in physical characteristics of waste types are also of major importance in designing a treatment facility. It has been noted that Dungeness and Tanner crab shells are more dense than that from King crab resulting in slower extraction of protein under the same processing conditions. Shrimp shell is more papery in texture and while its protein is readily extractible, "freeness" of the undissolved material is often reduced by felting of flaky chitin particles. Thus, while a battery of fixed bed diffuser cells might serve as extraction units for crab shells, it is doubtful if shrimp could be handled in such equipment. Butchering waste and fishery wastes would also be unsuitable for fixed bed treatment for the same reasons.

The optimum "product mix" produced by the treatment facility is also largely governed by differences in waste composition. There are a number of possibilities and these should be combined to provide the greatest return for the least cost. This will be more fully discussed under 5. Product Utility and 8. Economic Considerations.

In prior reports we have used ternary diagrams to represent waste compositions and changes resulting from processing. While these disregard minor components, they are useful to illustrate major differences. In Figure I the composition of shellfish wastes is presented summarizing analyses conducted under the present contract and previously obtained data. The relative percentages of protein and chitin have been calculated to allow for a lower nitrogen content for shellfish waste protein than the usual 16 percent assumed. A value of 15 percent agrees more closely with analytical values on protein and actual chitin yields.

The points on the Figure for King, Tanner and Dungeness crab are for picking line wastes. Inclusion of butchering wastes would lower the points on the Figure since relative amounts of protein and fat ("other") would be increased. A point is shown for red crab (Pleuroncodes planipes). This is a very small pelagic species occurring in semi-tropical waters in very large numbers. The point represents composition of the whole animal.

Lines extended from the protein apex to the opposite side of the Figure represent the protein extraction process. The composition of the chitin-$CaCO_3$ residue is represented by points at the side of the Figure. It is indicated that King crab waste would be a preferred material for chitin isolation; shrimp waste would give the highest protein yields; while Tanner and Dungeness crab are less desirable from both standpoints.

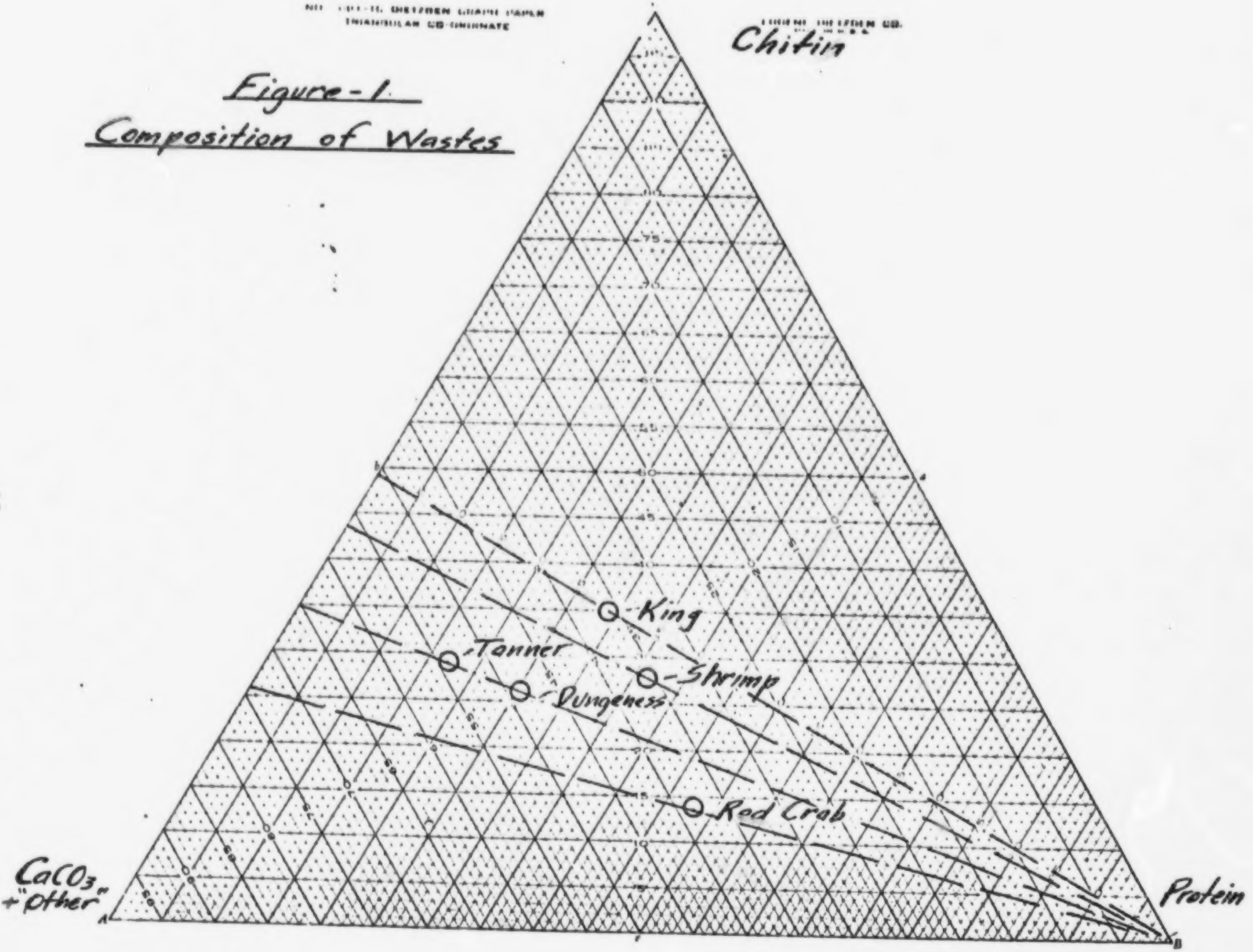
2. Factors Determining Rate of Protein Extraction

Rate studies have been conducted on extraction of Dungeness crab and shrimp wastes using two different procedures. In one the rate at which protein concentration approaches an equilibrium value is measured in a batch treatment at constant alkali concentration and temperature. This procedure has been found most useful to characterize the behaviour of different wastes and to determine effects of pretreatment, alkali concentration and temperature. Calculation of rate constants assumes that the rate of change of protein concentration at the interface between shell particles and ambient liquid is proportional to a driving force equal to the difference between protein concentration in shell interstices (P_s) and that at the interface (P_i).

$$d\,P_i/dt = K(P_s - P_i)$$

Further assumptions are that P_i is equal to the protein concentration in the ambient liquid and P_s is equal to the total unextracted protein dissolved in a constant interstitual volume equal to the water content of the moist shellfish waste. Values for P_s can thus be calculated from those for P_i and numerical integration can be employed to obtain that rate constant. This is equal to the slope of the line: $\log_e (P_s - P_i)/P_{so}$ versus time. Typical data plots are shown in Figure 2 for shrimp and Dungeness crab waste using different extraction conditions

Figure-1
Composition of Wastes



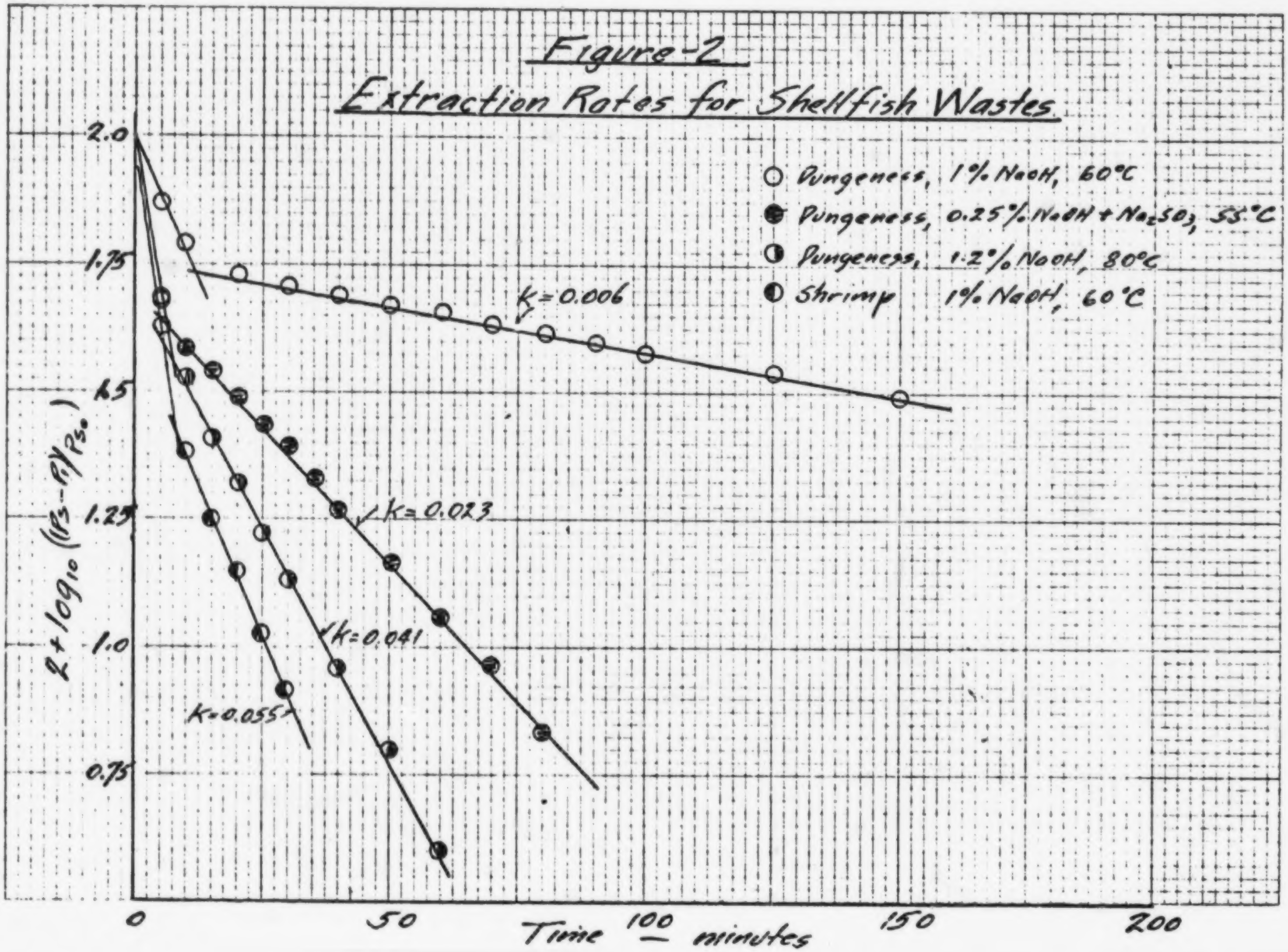


Figure-2

Extraction Rates for Shellfish Wastes

It is found that both shrimp and crab wastes show an initial period of very rapid extraction amounting to 30-50 percent of the total protein followed by a rather sharp break and a slow extraction period which fits the diffusion mechanism outlined above. This is undoubtedly an oversimplification of the true mechanism but serves to give a numerical index of the waste behaviour. It is noted that rate constants obtained for shrimp waste are considerably higher than for Dungeness crab under the same conditions, probably reflecting the density of the shell. It is also noted that temperature effects are higher than would be expected for strict diffusion dependence of the rate constants. This suggests chemical activation such as rupture of bonds between chitin and protein as being involved in the process. Alkali concentration does not appear to be an important variable. Sufficient alkali to satisfy the base binding capacity of the protein is necessary. This appears to be about 10 grams of sodium hydroxide per 100 grams of protein. Also a pH level of about 12.5 or higher appears necessary for the extraction since sodium carbonate solutions with concentrations up to 5 percent are relatively ineffective. Increases in sodium hydroxide concentration above about 0.5 percent do not produce proportional increases in extraction rate. Most recent experiments indicate that addition of sodium sulfite to the alkaline extraction liquor may have a specific effect in increasing the extraction rate as well as other beneficial effects.

The other procedure for study of extraction rates has been the determination of protein levels in eluates from percolation experiments in a fixed bed diffuser type reactor.

Results from this type of experiment are more difficult to interpret because more variables have to be considered such as flow rate and alkalinity. Alkalinity is not constant during the extraction because unextracted protein absorbs alkali during early stages of the experiment. A mathematical analyses of the elution process was developed (1, 2) which would allow prediction of elution rates from rate constants determined by the "approach to equilibrium" procedure. The treatment would be generally applicable to any fixed bed extraction process which is diffusion controlled and may prove to be of value should such types of processing become indicated.

3. Recoverability of Protein by Isoelectric Precipitation

Results from earlier experiments in July 1969 and prior indicated that the solubility of alkali extracted protein at its isoelectric point would be about 5 grams per liter (0.5 percent). To attain 95 percent protein recovery would thus require a protein concentration in the extract of 10 percent. This placed emphasis on the need for countercurrent treatment in order to build up the protein concentration in the extract to the desired level.

Subsequent studies have shown that protein solubility at the isoelectric point (actually, the pH of minimum solubility) is to some degree affected by the severity of the alkali treatment and to a very large degree is a linear function of the salt concentration. Since there is a minimum alkali combining capacity of about 10 percent for the extracted protein equivalent to about 14.6 percent of the protein as salt on neutralization, it is not possible to increase the protein concentration without increasing the salt concentration proportionally. (One could, of course, consider desalting procedures such as dialysis, ultrafiltration or ion exclusion, but these probably would not be economic in the process.) In addition, the added time of treatment to achieve high protein concentrations in the effluent would result in more degradation and more isoelectric protein solubility.

Above conclusions point to an extraction process in which alkali concentration, total alkali used, and time of contact are all minimized. In recent experiments these objectives have been approached and results have been encouraging. In one experiment an isoelectric protein solubility of 0.25 percent was attained at a salt concentration of 1.3 percent. This would amount to a protein recovery of 97.2 percent from an 8.9 percent protein solution, assuming minimum alkali consumption.

The use of sodium hexameta phosphate to complex and precipitate additional protein from the supernate as suggested by Mr. John Spinelli (3) of the Seattle B. C. F. laboratory also shows considerable promise. In one experiment protein solubility was reduced to 0.07 percent representing a recovery of 96.5 percent from a 2.37 percent protein solution.

Protein content of effluent from the process can be expressed as population equivalent in terms of biochemical oxygen demand in the following way:

Assume there is 8,800,000 pounds of 100 percent solids shrimp waste collected per year out of 65,000,000 pounds of raw shrimp with a five day BOD of 0.65 pounds oxygen consumed per pound of 100 percent solids waste. This amounts to 5.7 million pounds of BOD per year for collectable shrimp waste.

There is 4,800,000 pounds of 100 percent solids in collectable crab waste with a five day BOD of 0.63 pounds oxygen consumed per pound of 100 percent solids waste. This amounts to 3.0 million pounds of BOD per year for collectable crab waste.

The total for the two is 8.7 million pounds of BOD per year. With a 300 day season the average BOD per day from the collectable waste is 29,000 pounds or a population equivalent of 144,000 persons, assuming 0.2 pounds BOD per day per person.

A recovery of 95 percent of the collectable solids would reduce the population equivalent to 7,000 persons by utilizing this process.

This remaining five percent would be treated by conventional secondary methods further reducing the organic loading on the harbor.

4. Factors Influencing Protein Quality

In Table I data were presented on amino acid composition of spray dried crab and shrimp waste proteins in comparison with casein. This table is re-presented in the present report. It was found that the compositions of the two shellfish waste protein were quite similar although determined by two different laboratories using different procedures. They both compare favorably with casein in total essential amino acid content. The percentages of arginine and isoleucine are significantly higher for the shellfish proteins while casein shows higher values for valine and leucine.

Feeding tests have been conducted on rats using both the shrimp and crab waste proteins. Both show marked deficiency in sulfur-containing amino acids which can be corrected by supplementation with either cystine or methionine. In all other respects the shellfish waste proteins were found to be equal to casein in nutritional value and there were no toxic effects noted.

A sulfur balance on crab waste and on the extracted protein indicated that most of the sulfur in the waste is still present in the spray dried protein. (It should be noted however that a very slight odor of hydrogen sulfide has been detected during neutralization of alkaline extracts.) Based on assays for cystine and methionine (Table I), only about half of the sulfur found in the protein can be accounted for. It thus appears that sulfur-containing amino acids were present before extraction at about twice the level found by assay on the isolated protein.

Review of the literature(4,5,6,7) on effects of alkaline treatment on methionine and cystine in proteins suggests that methionine should be relatively stable in the treatment but that cystine can be largely and irreversibly converted to lanthionine which presumably has no nutritional value as a sulfur source. The exact mechanism for the reaction is not clear but the overall effect is the rupture of disulfide bonds with elimination of one atom of sulfur and recombination of residues in a thio ether linkage.

Cystine: $HOOC\text{-}CHNH_2\text{-}CH_2\text{-}S\text{-}S\text{-}CH_2CHNH_2\text{-}COOH$

Lanthionine: $HOOC\text{-}CHNH_2\text{-}CH_2\text{-}S\text{-}CH_2CHNH_2\text{-}COOH + S$

The form of the eliminated sulfur is not clearly established.

Normally, there is an equilibrium between cystine and cysteine residues in proteins determined by the presence of oxidizing or reducing conditions in the system. The formation of cysteine with free sulfhydryl groups may be an intermediate step in lanthionine reaction. If it is not, or if the sulfhydryl group can be blocked from recombining as thio ethers, the presence of a reducing agent should be beneficial in preventing lanthionine formation. Sulfite ion, either by shifting the equilibrium toward cysteine or by blocking recombination through formation of s-sulfo cysteine groups might serve this purpose.

Table I

Amino Acid Composition of Spray Dried Shellfish Waste Proteins

Sample	Dungeness Crab Protein		Shrimp Protein		Casein
	As rec'd Basis %	100% protein Basis %	As rec'd Basis %	100% protein Basis %	100% protein Basis %
Lysine*	5.4	6.35	6.24	8.34	6.02
Histidine*	2.21	2.60	2.22	2.97	2.31
Arginine*	5.5	6.47	6.04	8.06	2.41
Aspartic Acid	10.3	12.1	6.46	8.63	4.45
Threonine*	3.57	4.20	2.93	3.91	3.81
Serine	2.7	3.18	3.51	4.69	5.88
Glutamic Acid	12.3	14.5	13.3	17.8	21.90
Proline	4.33	5.10	3.40	4.54	15.71
Glycine	4.2	4.94	5.63	7.52	1.16
Alanine	4.6	5.41	5.35	7.14	1.47
Cystine	0.24	0.28	not detnd.	----	not detnd.
Valine*	5.5	6.47	4.21	5.62	7.91
Methionine*	1.97	2.32	1.95	2.60	2.75
Isoleucine*	4.7	5.53	3.87	5.17	3.91
Leucine*	6.6	7.78	6.10	8.14	11.07
Tyrosine	4.0	4.70	2.70	3.61	2.72
Phenylalanine*	4.07	4.80	3.78	5.05	5.46
Tryptophan*	1.0	1.18	0.55	0.73	Ca 1.0
Total	-----	97.9	-------	104.5	99.94

*essential

Experiments indicate that the presence of sodium sulfite during extraction does exert beneficial influences. These were noted in increased extraction rate (rupture of disulfide crosslinks?) and in improved appearance of the extracted proteins. Analytical results not available at the time of the above report now suggest that reduction in extent of cystine destruction may also have been achieved.

Cystine was determined by Vassel's modification of the Fleming reaction(8) on hydrolyzates of the spray dried Dungeness crab waste protein (see Table I) and of protein isolated from Diffuser Experiment No. 6.

Results showed 0.23 percent cystine in the Dungeness crab protein and 1.05 percent in the protein extracted in the cystine in the presence of sodium sulfite. It would appear that cystine destruction was reduced in the sulfite experiment.

5. Possible Utility of Products

Products which might be manufactured from shellfish and fishery wastes by the proposed process would include the following:

a. Shellfish meal
b. Spray dried precipitated protein
c. Evaporated protein concentrates
d. Protein hydrolyzates
e. Deproteinized shell
f. Chitin and derivatives
g. Bone meal

Wide ranges in specifications are possible for most of these products depending on differences in raw materials and processing conditions. Obviously, all of the production from a processing facility will have to be disposed of in some manner or other and the greatest return will result from the product mix producing the highest sales at the least overall cost. The optimum product mix will not be constant since raw materials will vary seasonally and markets will be subject to their usual instabilities.

The following observations on individual products will serve to summarize our present conclusions regarding product utility.

a. Shellfish

The economics of production of crude shellfish meal in Alaska have been frequently investigated and generally found to be unfavorable. For this reason it has not heretofore been considered as a desirable product from a waste treatment facility. However, there are arguments for providing capability of manufacturing such products. Pollution abatement will require that the facility receive and process all of the waste produced

Experiments indicate that the presence of sodium sulfite during extraction does exert beneficial influences. These were noted in increased extraction rate (rupture of disulfide crosslinks?) and in improved appearance of the extracted proteins. Analytical results not available at the time of the above report now suggest that reduction in extent of cystine destruction may also have been achieved.

Cystine was determined by Vassel's modification of the Fleming reaction(8) on hydrolyzates of the spray dried Dungeness crab waste protein (see Table I) and of protein isolated from Diffuser Experiment No. 6.

Results showed 0.23 percent cystine in the Dungeness crab protein and 1.05 percent in the protein extracted in the cystine in the presence of sodium sulfite. It would appear that cystine destruction was reduced in the sulfite experiment.

5. Possible Utility of Products

Products which might be manufactured from shellfish and fishery wastes by the proposed process would include the following:

a. Shellfish meal
b. Spray dried precipitated protein
c. Evaporated protein concentrates
d. Protein hydrolyzates
e. Deproteinized shell
f. Chitin and derivatives
g. Bone meal

Wide ranges in specifications are possible for most of these products depending on differences in raw materials and processing conditions. Obviously, all of the production from a processing facility will have to be disposed of in some manner or other and the greatest return will result from the product mix producing the highest sales at the least overall cost. The optimum product mix will not be constant since raw materials will vary seasonally and markets will be subject to their usual instabilities.

The following observations on individual products will serve to summarize our present conclusions regarding product utility.

a. Shellfish

The economics of production of crude shellfish meal in Alaska have been frequently investigated and generally found to be unfavorable. For this reason it has not heretofore been considered as a desirable product from a waste treatment facility. However, there are arguments for providing capability of manufacturing such products. Pollution abatement will require that the facility receive and process all of the waste produced by fishery operations in the locality at any given time. Provision should be made for overloads, and unforeseen processing difficulties through alternative processing procedures. Also rising interest in fish culture has attached new values to shellfish meals, particularly shrimp meal due to its astaxanthin content. This carotenoid pigment imparts a desirable pink coloration to the flesh of trout and other species. It is possible that limited premium markets for shrimp meal may develop in this area.

b. Spray dried precipitated protein

This would now appear to be the product offering the greatest promise for maximum return. Incorporation in canned and processed pet foods offers a large potential market. Several of the major pet food manufacturers have expressed interest in these products based on examination of samples. One manufacturer has indicated that they could absorb the entire production at Kodiak now estimated to be about 4.9 million pounds per year. The products might command a premium price over that justified by nutritional value due to odor and flavor characteristics. Other markets such as industrial uses and use in foods for poultry and livestock have not yet been investigated.

c. Evaporated protein concentrate

We currently view such products as lower cost outlets for protein materials which will not meet specifications of preferred products. Multiple effect evaporation is inherently cheaper than spray drying and the facility will probably have to process some types of fish offal not suitable for premium products. Conversion to a product somewhat like the concentrated "Fish solubles" of commerce at about 50 percent solids might be the most economic treatment for such materials. They could be marketed as feed ingredients or possibly for manufacture of liquid fish fertilizer which has a large demand in the home garden trade. About 900 tons of 50 percent solubles can be produced from the salmon waste generated by the 1970 Kodiak salmon pack.

d. Protein hydrolyzates

This represents another possible type of protein product. Alkaline solutions of protein are preferred media for tryptic enzyme fermentations and hydrolyzates might be marketable in specialty feed formulations or as nutrients in antibiotic manufacture.

e. Deproteinized shell

The calcium carbonate - chitin residue from protein extraction of shellfish wastes would be the largest tonnage product of a waste treatment facility. It would also probably be a product with a low price potential, requiring careful control of production costs such as expended labor, heat, storage and freight to permit marketing at a profit for the enterprise.

The preferred market would be as a raw material for chitin production but this would depend on development of markets for chitin and derivatives and the competitive position of deproteinized shell from Kodiak with raw shellfish wastes in localities where chitin production were to be undertaken. Assuming that there will be a net chemical cost for demineralization, analytical data presented in Figure 1 indicate that deproteinized King crab shell would be a preferred material for this market due to a higher ratio of chitin to calcium carbonate.

Studies conducted by Dr. Laughlin at the Palmer Experimental Station of the Alaska Department of Agriculture using samples submitted by our laboratories indicate that deproteinized shell has merit as a liming agent for Alaska soils. Further tests are scheduled for this year to evaluate its merits as a nitrogen and phosphate source for growing plants. No estimates are available at this time regarding the possible extent of such markets in Alaska or the probable delivered cost of the material in agricultural communities. One property of the deproteinized shell which may be an asset in such markets is its microbiological stability. We have found that unlike raw shell, the deproteinized residue can be left in moist conditions at ambient laboratory conditons without putrefaction for several weeks. This might permit bulk shipment and cheaper handling costs. The amount of chitin-$CaCO_3$ resulting from the 1970 shrimp and crab pack in Kodiak is in the order of 4,300 tons.

f. Chitin and derivatives

Due to its insolubility, no important uses have been developed for chitin as such. It can however, be converted to soluble derivatives such as chitosan for which many uses have been suggested. These include formation of fibers and films, coatings for paper and for glass fibers to permit dyeing, encapsulation agents for pharmaceuticals, viscosity control agents for drilling muds, thickeners for printing inks, textile sizing materials and many others. We have found thirty or more U. S. Patents covering derivatives of chitin and uses in above and similar applications. Most of these patents were never explcited due to unavailability of chitin at reasonable cost. Until recent years shellfish wastes were not available in a single locality in quantities sufficient to produce chitin in volume and processes for its isolation without protein recovery resulted in too high a cost to compete with alternative material.

One new use of chitin derivatives which promises to supply a large volume market is as cationic polyelectrolytes for water and waste treatment. We have found that chitosan (deacetylated chitin) compares favorably with synthetic polydectrolyte materials (polyacrylamides and polymerized quaternary ammonium compounds) as a coagulant and coagulant aid for removal of turbidity from municipal and industrial waters. Due to current concern with water pollution and the coming need for water re-use a rapidly expanding demand for such products can be predicted. Economic considerations indicate that chitosan could be offered competitively with other polyelectrolyte materials. Its non-toxic character and biodegradability should act in its favor.

g. Bone meal

Alkali extraction of protein from fishery wastes such as herring, scrap fish and halibut trimmings will leave a residue of bone which could be dried and ground and marketed as bone meal. In our experiments on herring waste a product was obtained containing about 60 percent tricalcium phosphate and 25 percent residual protein. Indicated production of such material would probably be only two or three hundred thousand pounds per year but it should be readily marketable as a home gardening aid. Possibly blends with deproteinized shell would be marketable in the same field.

h. Fat concentrates

In processing picking line wastes from crab and shrimp production very little fat has been encountered. Some fat is emulsified with the alkaline protein extracts from shrimp wastes but this appears to be carried down with the protein during iso-electric precipitation. The treatment of crab butchering wastes and fishery wastes will presumably increase the amount of fat in the process and means for handling it will have to be provided. It is believed that centrifugal clarification of alkali extracts will separate the fats and that they would be dried by evaporation. Possible marketing as a feed additive should be investigated. Production should not be greater than 25,000 gallons per year.

6. Processing Equipment Indications

The varied nature of raw materials to be handled by the waste treatment facility with resultant changes in processing procedures and conditions suggests that processing equipment should be designed as a collection of unit operations rather than as a closely coordinated, continuous process such as would be preferred with a fixed raw material and a standard product. With this concept in mind, major equipment which would be needed by the facility would be as follows:

a. Collection System

Separate holding hoppers holding the screened waste would be needed at individual or groups of processing plants which operate on different products simultaneously. Shrimp waste should be separated from crab waste. Fish offal would not be mixed with shellfish wastes. Barges transporting wastes could be compartmented or could make separate hauls for different waste types.

b. Receiving Station

Separate dump pits should be provided for different waste types received simultaneously. Conveyors would deliver wastes to hammer mill type grinding equipment. Effluent from shellfish grinding would be passed over graded screens to retain particulate matter and discharge waste-water. (This will be treated by conventional secondary treatment before final discharge into recovery waters.) Fish offal slurries from the grinder would pass directly to an alkali extraction unit.

c. Fish Offal Treatment

Separate equipment would be needed for fish offal and shellfish waste. Fish offal slurries would be batch treated in a tank with slow agitation adding just sufficient alkali to dissolve proteins and holding at 50-60°C for about 30 minutes. Liquor would be drained through screens to remove bone fragments and passed through a centrifugal clarifier to remove fats after partial neutralization. A 50 percent solids "solubles" product would be made from the liquor.

Bone would be collected and washed in centrifugal equipment, and then dried in a rotary drum drier. The same drier could be used for deproteinized shell or for crude shellfish meal depending on possible scheduling of production. Drying would be followed by final grinding and bagging operations.

d. Shellfish Waste Treatment

Ground shellfish waste from collection screens would be fed to a set of probably five extraction units operated with continuous countercurrent flow of liquor and shell. Units would be horizontal cylindrical shells with internal screws designed to mix liquid and solid phases and to move solids through the unit. Alkali addition, temperature and residence time would be programmed in each stage to obtain an optimum balance between extraction rate and severity of treatment. The last stage of solids treatment would be essentially a washing stage. Most of the alkali would be added in the first stage of solids treatment to take advantage of the rapid extraction rate possible for 30 to 50 percent of the protein in the raw shell. Concentrated liquor from the solids treatment would be cooled in a heat exchanger, then centrifugally clarified and neutralized to its isoelectric point. Protein would be collected on a vacuum filter-washer, reslurried in water and spray dried. Filtrate from protein recovery would be discharged to the secondary sewage disposal plant. Deproteinized shell would be given a final neutralizing wash and dried in a rotating hot air drier. The extent of drying would depend on requirement for storage and shipment.

7. Pollution Abatement

As mentioned in the introduction, the yield of edible meat from shellfish processing amounts to from 17 percent live weight for small machine peeled shrimp to about 27 percent for larger crab species, with the remainder being waste.

In the City of Kodiak there are 14 plants processing shrimp, King crab, Tanner crab, Dungeness crab, salmon, halibut, herring and scallops.

Two plants process six of these eight items during the course of their season with the rest of the plants processing two or more items. These plants are located along a two and a half mile section of the waterfront of the City of Kodiak.

Table II shows the amount of shrimp processed by these plants in 1970, while Table III and IV show the production of crab and salmon processed.

Table II

Shrimp Processed - 1970
(Million of lbs.)

Month	Plant 1	Plant 2	Plant 3	Plant 4	Total
Jan.	2.00	0.71	0.80	1.19	4.70
Feb.	2.00	0.42	0.80	0.78	4.00
March	2.50	0.35	0.80	0.86	4.51
April	2.60	0.58	0.80	0.91	4.89
May	1.50	0.07	0.40	0.44	2.41
June	3.30	0.64	0.70	1.39	6.03
July	3.90	1.16	1.40	1.90	8.36
Aug.	3.90	0.89	1.30	1.62	7.71
Sept.	3.90	0.66	1.00	1.14	6.70
Oct.	3.00	0.58	0.80	0.78	5.16
Nov.	2.20	0.60	0.80	0.80	4.40
Dec.	1.70	0.51	0.80	0.73	3.74
Total	32.50	7.17	10.40	12.54	62.61

Table III

Crab Production in 1970
for the Kodiak Area by Months

Millions of pounds - Live weight

(Alaska Dept. of Fish and Game)

	Kodiak Area			City of Kodiak (80%)			
Month	King	Tanner	Dungeness	King	Tanner	Dungeness	Total
January	1.29	0.71	-	1.03	0.57	-	1.60
February	-	1.21	-	-	0.97	-	0.97
March	-	2.73	-	-	2.19	-	2.19
April	-	1.74	-	-	1.39	-	1.39
May	-	0.76	0.16	-	0.61	0.13	0.74
June	-	0.18	0.73	-	0.14	0.59	0.73
July	-	0.14	1.91	-	0.11	1.53	1.64
August	1.69	-	1.51	1.35	-	1.21	2.56
September	3.69	0.01	0.78	2.95	0.01	0.62	3.58
October	2.47	0.01	0.49	1.98	0.01	0.39	2.38
November	1.73	0.12	0.13	1.38	0.10	0.10	1.58
December	1.22	0.14	0.02	0.98	0.11	0.02	1.11
Total	11.81	7.75	5.73	9.67	6.20	4.58	20.47

Table IV

1970 Salmon Production at Kodiak

Week Ending	Cases Packed 48 lbs. each	Frozen Salmon lbs.
6-13	1,781	-
6-21	1,232	95,280
6-28	17,508	74,664
7-5	789	27,270
7-12	14,774	77,402
7-19	37,838	257,356
7-26	34,835	392,827
8-2	40,006	371,214
8-9	26,714	275,276
8-16	10,612	19,829
8-25	13,131	61,164
8-30	5,314	562,417
9-6	514	-
9-13	-	399,709
Total	205,048	2,614,408

As presently practiced this waste is dumped into Kodiak Harbor. As a result of this present discharge of over 73 million pounds of waste there is up to four feet of residual organic matter in Kodiak Harbor. While it has not been definitely established that this waste load is totally harmful to the environment (some fisheries experts believe that a part of it is food for other marine organisms in the food chain) the practice does not comply with the water quality standards of the State of Alaska.

As you may know these laws state that all wastes dumped into receiving waters must have secondary treatment unless an engineering report shows primary treatment is adequate.

To treat this entire waste load by secondary treatment is a gigantic undertaking as up to 5 million gallons of water per day are consumed by these 14 processors, spread along two and a half miles of waterfront. This is complicated by the fact that no land is presently available for such a plant along this area except an island located 600 feet across a channel from the nearest mainland. We therefore, have been measuring the organic loading of crab and shrimp wastes.

Table V shows the estimated loss of solids from crab processing as a result of our process. This represents the cooking and washing solids not collected by a 40 mesh screen. The visceral material together with their wash waters are to be collected in their entirety to avoid their introduction into the receiving waters. If this is followed only 7.3 percent of the total solids from the crab processing operations will be lost.

Table VI shows the estimated loss of solids from shrimp processing as a result of our process. This represents the cooking and washing solids not collected by a 40 mesh screen. The collectable solids are 64.4 percent of the total waste load with 60 percent of the COD retained.

As all of the waters from the salmon canning operations are to be collected their contribution to the pollution load will be negligible. This amounts to 40 percent of the live weight catch or 6.44 million pounds of wet wastes per year or 1.3 million pounds of solids.

The total pollution abatement by using this process is shown in Table VII. This shows that 73.8 percent of the total pollution load of 20.2 million pounds of 100 percent solids waste can be eliminated from Kodiak Harbor by using this process.

8. Economic Considerations

Based on the 1970 production figures, there will be 13.6 x 10^6 pounds of shellfish solids collectable in Kodiak. Of this, 8.8 x 10^6 are shrimp and 4.8 x 10^6 are crab solids. Using an average of 40 percent

Table V

CRAB

20 MILLION POUNDS/YEAR
LIVE WEIGHT

	100% Solids	%
LOSSES		
Not caught by screening	3.8×10^5 #	7.3
COLLECTABLE WASTE SOLIDS FOR PROTEIN RECOVERY		
69% of catch as picked meat	2.02×10^6 #	38.8
25% of catch as leg sections	1.93×10^6 #	37.2
6% of catch as whole cooked crab	0	0
COLLECTABLE WASTE SOLIDS FOR SOLUBLES RECOVERY		
69% of catch as picked meat	$.64 \times 10^6$ #	12.3
25% of catch as leg sections	$.23 \times 10^6$ #	4.4
6% of catch as whole cooked crab	0	0
TOTAL COLLECTABLE	4.8×10^6 #	92.7
TOTAL SOLIDS	5.20×10^6 #	100%

Table VI

SHRIMP PROCESSING
63 MILLION POUNDS/YR. LIVE WEIGHT

	# X 10^6	%	#COD X 10^6	%
LOSSES				
Not caught by screening (100% Solids)				
Peeled raw & cooked	3.8		4.1	
Cooked & peeled	1.1		1.5	
TOTAL	4.9	35.6	5.6	40.0
COLLECTABLE WASTE SOLIDS 100%				
Peeled raw & cooked	6.1		5.8	
Cooked & peeled	2.7		2.6	
TOTAL	8.8	64.4	8.4	60.0
TOTAL WASTE SOLIDS	13.7		14.0	

Table VII

TOTAL POLLUTION ABATEMENT

	# @ 100% Solids X 10^6	%
LOSSES		
Shrimp Waste	4.9	24.2
Crab Waste	0.4	2.0
Salmon Waste	0	0
	5.3	26.2
COLLECTABLE WASTE		
Shrimp	8.8	43.5
Crab	4.8	23.8
Salmon	1.3	6.5
	14.9	73.8
TOTAL	20.2	100%

protein from shrimp and 30 percent protein from the crab. We can recover 3.5 x 10^6 of shrimp protein and 1.4 x 10^6 pounds of crab protein per year by using this process. The indicated market price for this protein is 15¢ per pound F.O.B. Kodiak on a 100 percent solids basis making the market price for this product $735,000.

The salmon waste of 1.3 x 10^6 pounds would produce 300,000 pounds of oil worth $24,000; 200 tons of bone meal worth $40 per ton or $8,000; and 900 tons of 50 percent solids salmon solubles worth $30.00 per ton or $27,000.

The crab butchering waste and scrap fish associated with the shrimp trawls of 8.7 x 10^5 of solids would produce an additional 1,600 tons of solubles worth $48,000.

The residual calcium carbonate-chitin complex of 4,300 tons is worth at least $10.00 per ton or $43,000 F.O.B. Kodiak for its lime value alone and worth considerably more when markets open up for chitin as an industrial chemical. The total worth of these products is $837,000.

The plant will have to convert a maximum of 100 tons of wet shell residues plus the crab butchering waste and miscellaneous scrap fish associated with the shrimp into products each day during the height of the season in August.

It also must process the salmon waste which peaks during this time. They average 100 tons per day during this period.

For these reasons the plant would have to handle 200 tons of wet waste during a 20 hour period or 10 tons per hour. Such a plant is estimated to cost in the neighborhood of $1,000,000 based on the costs of a 25 ton per hour conventional fish meal plant built in the continental United States for a cost of $1,000,000.

Unfortunately at the time of this paper the total economic study of the process has not been completed. However, based on the rough estimates, this process appears to be profitable at Kodiak with the profitability dependent on the method of financing, interest rates, inflation due to labor and materials and other factors not yet determined.

CONCLUSION

A final report under EPA Grant 11060-FJQ is forthcoming in the near future and will at this time have the total economic study with recommendations as to its implementation. The proposed facility would collect and treat all of the fisheries waste generated in the Kodiak vicinity. Without the help of the Environmental Protection Agency and the City of Kodiak and the fisheries processors this development could not have occurred. Hopefully, a means has been found to eliminate pollution at Kodiak which may be also applicable in other shellfish processing localities.

It may develop that recoveries of these wastes can generate profits so that a present liability can be a future asset at the same time abating pollution.

References

1. T. E. W. Schumann, J. Franklin Institute, 208:405 (1929)
2. C.C. Furnas, Trans American Society of Chemical Engineers, 24:192
3. John Spinelli and Barbara Koury, Journal of Agriculture and Food Chemistry, 18:284 (1970)
4. Horn, M. J., Jones, D.B. and Ringel, S. J., J. Biol Chem 138:141 (1941)
5. Cuthbertson, W. R. and Philips, H., Biochem, J., 39:7 (1945)
6. Lindleg, H. and Philips, H., Ibid, 39:17 (1945)
7. Blackburn, S. and Lee, G. R., Biochemica et Biophysica Acta, 19:505 (1956)
8. Block, R. J., Amino Acid Composition of Proteins and Foods Springfield, Illinois (1945)

SALT RECLAMATION FROM FOOD PROCESSING BRINES

by

E. Lowe and E. L. Durkee*

Pickling is one of the oldest forms of food preservation known to man. In this age of radiation sterilization, freeze concentration, microwave drying and other forms of high technology processing, it is interesting to note that the pickling industry in this country keeps rolling along, producing anywhere between a billion and a billion and a half pounds of pickled products a year. Most of this production consists of cucumber pickles, but other foods are also pickled, including: onions, pepper, beets, snap bean, cauliflower, tomatoes, crab apple, olives, corn, cabbage, nuts, fruit peel, meat and fish. The Northern and Southern states, principally Michigan, Wisconsin and North Carolina produce over 80 percent of the cucumber pack, but California ranks third among the producing states, behind Michigan and North Carolina.

The production of pickled products involves a salting operation in which the freshly harvested material is stored in salt brine and allowed to ferment before further processing. In cucumber pickling, for example, the brine initially contains about 10 percent NaCl. After 4 to 6 weeks, the concentration is gradually increased to a final value of from 15 to 20 percent, at the rate of from a half to 1 percent per week.

Each year, the pickling industry generates up to 100 million gallons of used brine from its salting operations. The disposal of this amount of saline liquid waste without causing water pollution has become a problem of increasing urgency to the industry. The corrosive nature of the sodium chloride salt in the brine, and the fact that the waste stream is a mixture of a non-biodegradable salt and organic solids, makes the disposal problem a particularly difficult one.

In California, the olive industry has been particularly hard hit by the demands for pollution control. In response to this situation, we have been studying the possibility of reclaiming the process salt for reuse. The method we have devised was designed specifically for the reclamation of olive processing brines, but the chances are good that it will also be effective for the treatment of brines from some of the other products that I have mentioned.

Now olives are salted in much the same way as cucumbers. The concentration of the salt brine used depends on the variety of olive and ranges from 3 to 5 percent initially. The concentration is gradually increased over a period of 3 to 4 weeks to a final level of from 7 to 9 percent,

---

*Western Regional Research Laboratory, Agricultural Research Service, U. S. Department of Agriculture, Berkeley, California

Preceding page blank

again depending on the variety. Most olives are stored in brine for a period of from 1 to 6 months.

Several methods have been suggested for reconditioning the used brine, but because the used brine is more concentrated than the starting brine, recovery of at least a portion of the salt as a solid is essential if there is to be no residual waste stream. This can only be done, of course, by evaporating the water.

Decontamination of the salt or salt solution is the other major problem in reclaiming brine for reuse. Interestingly enough, the solution to this problem is facilitated by the requirement that the salt be in solid form. Figure 1 shows a salt recovery and decontamination method that has been under study at the Western Regional Research Laboratory, USDA, at Albany, California.

EVAPORATION BY SUBMERGED COMBUSTION

In this new process, a submerged combustion evaporator is used to crystallize the salt from the used brine solution. Submerged combustion is a method for heating liquids by passing the gaseous products of combustion from a burner directly up through the liquid body. Heat is rapidly transferred from the rising gas bubbles to the liquid through the bubble interface. The partial pressure of the water vapor in the rising bubble is less than one atmosphere so that boiling takes place at a temperature considerably below the normal boiling point for a saturated NaCl solution, 227°F. The observed equilibrium temperature is about 200°F, corresponding to a depressed vapor pressure of about 443 mm, and a heat of evaporation of approximately 978 BTU/lb.

Conventional evaporators can, of course, be used to crystallize the salt, but there are several drawbacks to this approach. For one thing, capital costs are several times greater for a conventional evaporator than for a submerged combustion unit. This is particularly true for an evaporator handling a saturated NaCl solution because of the extremely corrosive nature of the solute. Because there are no heat transfer surfaces in a submerged combustion heater, equipment cost is comparatively low.

The absence of any heat transfer surface works in favor of the submerged combustion heater in another way. No surface, no fouling.

The disadvantage of submerged combustion is a lower thermal efficiency as compared to a multiply effect evaporator simply because it is not practical to recover the heat energy in the exhaust vapor stream. Theoretical combustion shows a calculated thermal efficiency of 86.7 percent for the crystallization of salt from an 8.5 percent NaCL brine solution, based on the gross heat content of natural gas, and 96.8 percent based on the net heat content.

DECONTAMINATION BY INCINERATION AND FILTRATION

The slurry leaving the bottom of the crystallizer contains about 57.5 percent solids (see Table 1) of which 6% is combustible organic matter that

	Feed Brine	Salt Slurry	Incin. Salt	Recond. Brine
Sp. gr.	1.062			1.026
pH	3.7	4.1		10.0
Solids , %	9.6	57.5	100.0	4.0
Na Cl, % (dwb)	84.1	91.3	98.3	100.0
K, % (dwb)	4.0	1.3	2.7	0.9
Ca, % (dwb)	0.1	0.1	0.1	—
Sulphates, % (dwb)	0.5	0.6	0.7	0.4
Protein, % ($N_{dwb} \times 6.38$)	2.25			<.06
C.O.D., ppm	34,700			25

Table 1. Chemical Analyses of Brines, Slurry and Salt.

must be eliminated before the salt is suitable for reuse. In Figure 1, the organic contaminants are destroyed by incineration at a temperature of approximately 1200°F. After 5 minutes in the incinerator, the salt is decontaminated except for a small amount of carbon residue from the incineration. The reclaimed salt is best stored in this form from one season to the next, thus releasing the wood storage tanks for sweetening during the off-season by the conventional lime treatment.

Figure 2 shows the solids at various stages of treatment: the slurry of crystallized salt, the incinerated salt and the carbon sludge which is filtered from the reconditioned brine.

Brine for the following season's pack is prepared by dissolving the proper amount of incinerated salt in water to produce a 3 to 5 percent solution. HCl is added at this point to neutralize the reconditioned brine, which otherwise has a pH of 10.0 (see Table 1). The carbon is separated from the salt solution by simple filtration, leaving a clear brine (see Figure 3) free of organic matter (see Table 1). If time is of no great importance, the salt solution can be clarified by allowing the carbon residue to settle out by gravity. Depending on the depth of the vessel, this might be a matter of several hours.

COST ESTIMATES

Preliminary cost estimates were made for a plant handling 250,000 gallons of 8.5 percent brine over a period of 40 8-hr days, using natural gas as fuel. On the basis of 100 gallons of brine per ton of fresh olives (3), this represents a plant processing approximately 2,500 tons of fruit a year.

The estimates indicate a reclamation cost of $42.47 per ton of salt or $1.60 per ton of olives, which includes a first year capital cost of $16,500 amortized over a period of ten years, and a fuel cost of $13.34 per ton of salt. This compares with fresh salt at $13.40 a ton, to which must be added an average shipping charge of $0.43 per hundred-weight, and a brine disposal charge of $0.20 per thousand gallons (3), for a total cost of $22.53 per ton of salt delivered, or $0.86 per ton of fruit processed.

For the average plant, the additional cost for a substantial contribution to pollution control is something under $2,000 a year for the first ten years. After that, instead of an added expense, there is a small potential savings of about $430 a year. In view of the increasing pressure on conventional methods of liquid waste treatment, the cost of brine disposal will no doubt increase sharply in the days to come, so that the dollar difference should continue to improve in favor of salt reclamation.

It is obvious that some additional expense will be involved in reclaiming the salt for reuse, but the small additional cost per ton of fruit is perhaps well justified by the greater benefits that accrue to society as a whole.

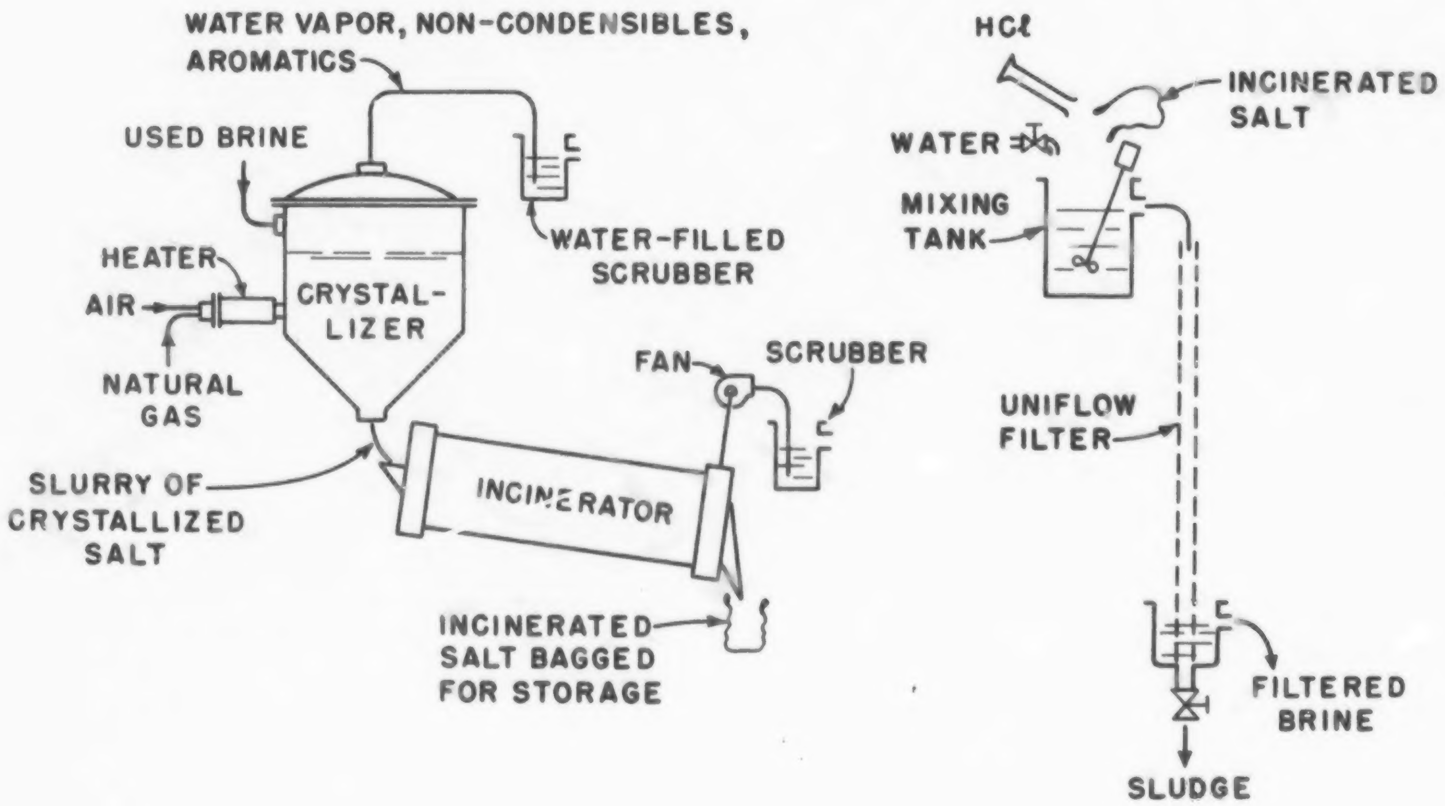


Figure 1. Flowsheet Showing Process for the Reclamation of Salt from Food Processing Brines

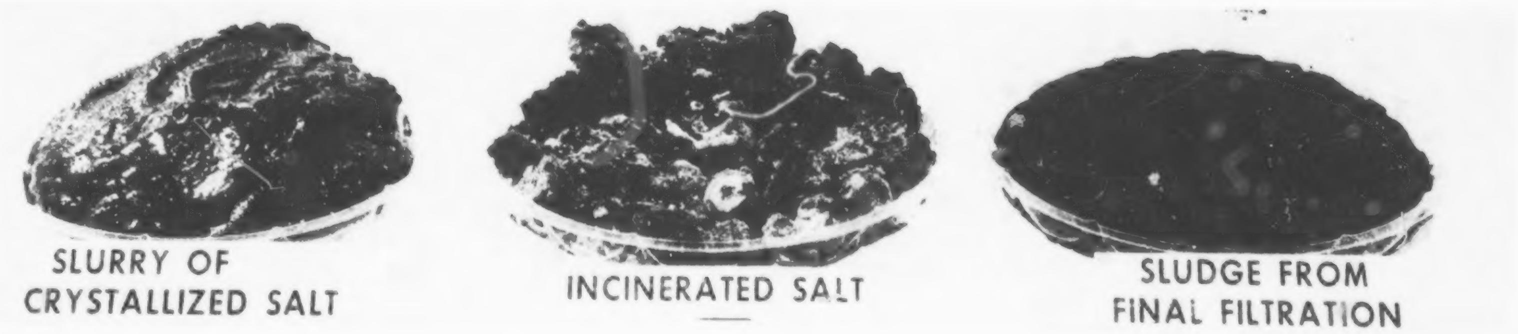


Figure 2. Slurries and Solids at various stages of Treatment.

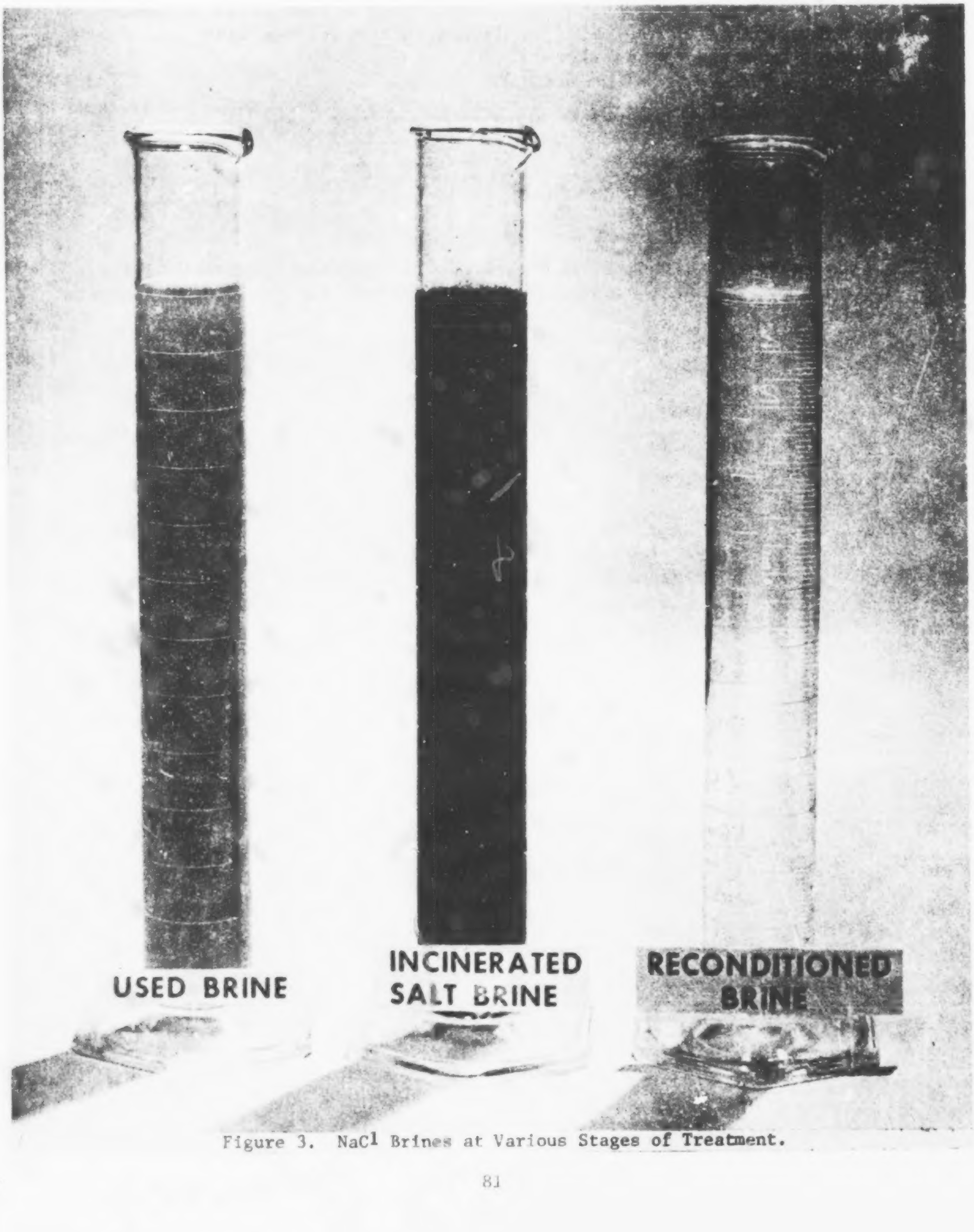


Figure 3. NaCl Brines at Various Stages of Treatment.

STORAGE EXPERIMENTS

Experiments are currently underway to evaluate the quality of the brine made from salt recovered from the previous year's brine. This will be followed by larger scale experiments involving the storage of freshly harvested olives in salt brine reclaimed from the 1970 waste stream. These storage studies are being conducted in cooperation with the NCA Laboratory in Berkeley, California.

Tests are also being made with cucumber pickling brines and so far, the results look very encouraging.

ACKNOWLEDGMENTS

The authors wish to thank E. D. Ducay for the chemical analyses of the brine, slurry, and salt samples, and J. S. Hudson for the C.O.D. analyses.

REFERENCES

1. National Canners Association. Investigations on the effect of variations in processing on ripe olive flavor, NCA Report No. D-3051, October 1968.

2. Popper, K., Camirand, W. M., Watters, G. G., Bouthilet, R. J., and Boyle, F. P. Recycles process brine prevents pollution, Food Engineering 39(4): 78-80, April 1967.

3. National Canners Association. Reconditioning of food processing brines, NCA Report No. D-2297, May 1970.

REDUCTION OF SALT CONTENT OF FOOD PROCESSING LIQUID WASTE EFFLUENT

by

Dr. Jack W. Ralls, Walter A. Mercer, and Nabil L. Yacoub*

INTRODUCTION

Sodium chloride brines have been used in a number of food processing operations for many years. Brines are used for preparation of ground meats, hams, bacon, and corned beef, for storage of fermented foods, and for quality grading of vegetables such as green beans and peas. The weight of sodium chloride used in 1960 by the food processing industry was approximately 1.1 million tons (Heid and Joslyn, 1967); most of the salt was used by the meat packing industry.

Salt used in foods as a flavoring ingredient provides the major portion of the approximately 10 grams consumed daily by each person in the United States. The 1000 tons of sodium chloride excreted dialy in urine by the population of the United States is eventually deposited in receiving waters. There is little expectation of changing the gradual increase in salinity of receiving waters due to the ingestion and excretion of sodium chloride during normal human physiological processes. Fortunately, there are promising technological developments which should reduce the potential salinity increase of receiving waters from industrial operations using salt.

The fermented food, especially pickles and olives, are unique among food processing operations using substantial quantities of salt because most of the salt is separated from the final product and discarded as a liquid waste. In many areas of the United States, salt brines from fermented food preparation are discharged to sanitary sewers where the incremental sodium chloride load which they contribute does not substantially increase the total dissolved solids level in the effluent from the treatment plant. In other areas, the total dissolved solids in treatment plant effluent become excessive due to lack of dilution of the processing brines with sanitary sewage or industrial wastes low in sodium chloride. One such area, where potential saline pollution of receiving waters is of concern, is in the Central Valley of California. Here are located a number of olive processing plants, usually in small towns, which generate substantial volumes of liquid waste containing sodium chloride and sodium hydroxide. The bulk of the salt used in olive processing is contained in the storage brines for freshly harvested olives. These relatively low volume, high salt content, brines can be managed by ponding or by reconditioning and reuse (Mercer, et al., 1970; Lowe and Durkee, 1971). It is the large volume, lower salt content, processing and rinsing brines which present a more challenging waste management problem.

---

*Western Research Laboratory, National Canners Association, Berkeley, California

Preceding page blank

New processing technology such as in-the-jar fermentation of pickles and olives (Etchells, et al., 1964, 1966) and salt-free storage of olives (Vaughn, et al., 1969) may provide solutions to part of the potential saline pollution from pickle and olive production. In the case of olives, it is still necessary to use sodium hydroxide to hydrolyze bitter olive constituents, so the problem of management of large volume, low salt content, processing waters still must be solved.

ION EXCHANGE TREATMENT OF SALINE OLIVE PROCESSING WASTEWATERS

Ion exchange is the most promising method currently available to treat saline wastes such as olive processing waters which contain dissolved organic compounds as well as inorganic salts. There are five ion exchange processes which have been proposed for water desalination. The characteristics of these processes are tabulated in Table I.

Table I

Comparison of Competitive Ion Exchange Processes for Water Desalination

Name of Process	TDS in feed, ppm	Operation Scale, mgd	Cost $/1000 gallons
Sul-bi-Sul	100-1000	5	0.29
Desal	150-10,000	5-10	0.13-0.78
Sirotherm	1000	5	0.25
Asahi-Grover	1000	5	0.25-0.35
Aqua-Ion	100-10,000	0.4	0.13-0.17

It is clear from an examination of the information summarized in Table I that the Aqua-Ion process has a lower cost (at a much smaller scale of operation) than the other processes listed. The low cost at small scale of operation is very important because the maximum output of dilute saline waste from a single olive processing plant would probably not exceed 500,000 gpd. Figure 1 is a photograph of the pilot unit which was constructed by Aqua-Ion to treat up to 10,000 gpd of saline waste under contract to NCA in an Environmental Protection Agency supported project. Figure 2 is a schematic representation of the Aqua-Ion pilot unit; specifications of the unit are tabulated in Table II.

The treatment consists of passage of waste effluent over a mixed bed of cation and anion exchange resins. The cation exchanger was in the calcium form and was a sulfonated polystyrene resin (Duolite C-20). The anion exchanger was in the hydroxyl form and was an aminated polystyrene resin (Duolite A-102-D). The polar constituents of the waste, shown for simplicity as sodium chloride, react with the exchangers as follows:

$$\text{(cation)}\ R_2Ca + 2\,NaCl \longrightarrow 2\,RNa + CaCl_2$$

$$\text{(anion)}\ 2\,ROH + CaCl_2 \longrightarrow 2\,RCl + Ca(OH)_2$$

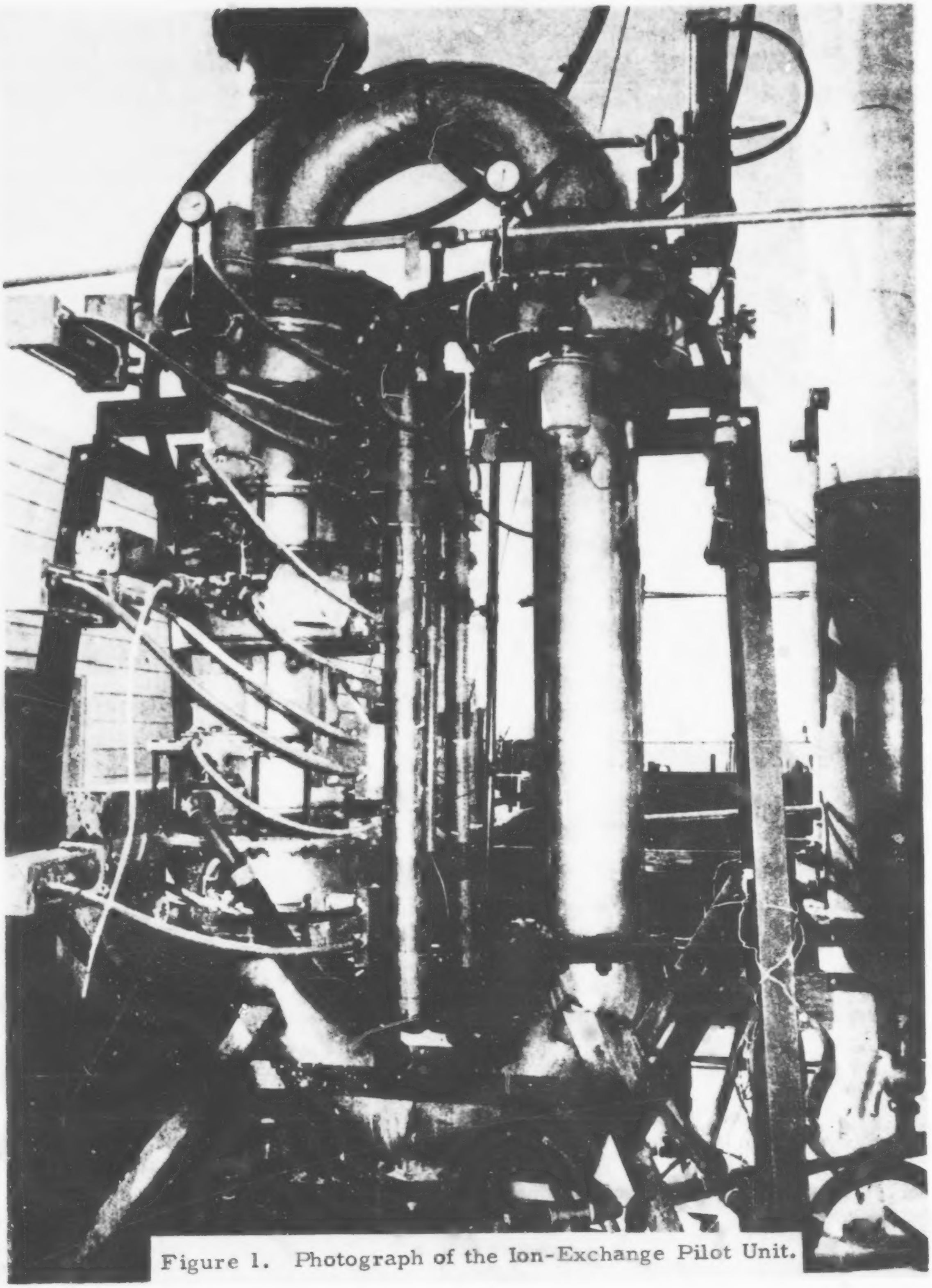


Figure 1. Photograph of the Ion-Exchange Pilot Unit.

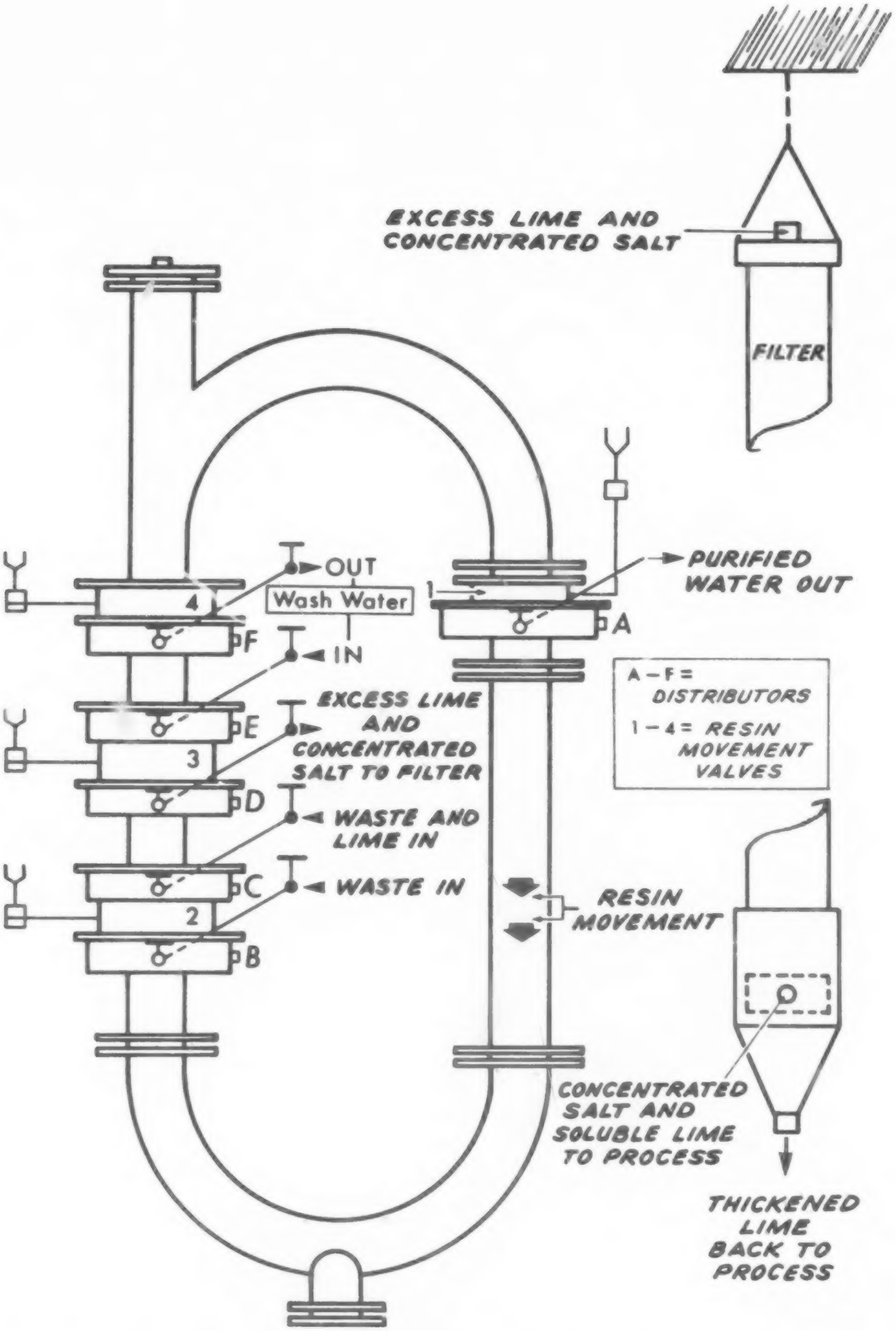

EXCESS LIME AND CONCENTRATED SALT
FILTER
OUT
Wash Water
IN
4
F
E
3
D
C
2
B
1
A
PURIFIED WATER OUT
A – F = DISTRIBUTORS
1 – 4 = RESIN MOVEMENT VALVES
EXCESS LIME AND CONCENTRATED SALT TO FILTER
WASTE AND LIME IN
WASTE IN
RESIN MOVEMENT
CONCENTRATED SALT AND SOLUBLE LIME TO PROCESS
THICKENED LIME BACK TO PROCESS

Figure 2. Schematic Representation of the Ion-Exchange Pilot Unit.

Table II

Specifications of the Aqua-Ion Exchange Pilot Plant

Higgins Loop Diameter: 1 ft

Height of Desalination Leg: 9 ft

Resin Volume: 17.3 cu ft

Exchanger Ration: 65 percent cationic
35 percent anionic

Resin Movement Per Cycle: 22 in.

Uni-Flow Filters: Primary - 20 hoses
Secondary - 7 hoses

Power Rating: 7 horsepower

Depending on the solute concentration, the calcium hydroxide formed during the removal of sodium chloride will stay in solution or (if the concentration exceeds 0.0443 N at 25°C) will precipitate. The precipitated calcium hydroxide (and other insoluble salts) can be removed using an Uni-Flow filter (Popper, 1970). These filters are inexpensive and simple to use. The slurry enters the filter distributor at the top and flows down through the individual hoses. The clear liquid passes through the cloth and runs down the outside of the hose to a collection point. The sludge moves along inside the hose and is discharged periodically at the bottom.

The product of the ion exchange operation is a solution of calcium hydroxide and organic material. Part of the organic material originally present in the waste is converted to insoluble organo-calcium salts which can be removed by filtration. The calcium hydroxide can be removed from the ion exchange effluent by carbonation and filtration of the resulting calcium carbonate or by ion exchange of the calcium for magnesium. Formation of insoluble magnesium hydroxide to remove calcium hydroxide is feasible in locations where either the wastewater or the water supply contains high levels of magnesium. In locations which have high bicarbonate hardness, the effluent from the ion exchange unit can be blended with hard water to produce cold lime softening as shown by the following equation:

$$Ca(OH)_2 + Ca(HCO_3)_2 \longrightarrow 2\ CaCO_3 + 2\ H_2O$$

The resin must be regenerated to convert it into a form usable for further sodium chloride removal. Regeneration is accomplished with a solution or suspension of calcium hydroxide in the saline wastewater. The regenerant effluent is saturated with calcium hydroxide and contains the salts and part of the organic compounds originally present in the saline wastewaters. The regenerant is recycled many times in order to increase the sodium chloride concentration to a level which makes salt recovery or reuse attractive eonomically. The regenerated resin is rinsed with tap water to remove residual calcium hydroxide and is then ready for treatment of saline wastewater. Figure 3 shows a flow diagram of the complete ion exchange and regeneration operation.

OPERATION AND EVALUATION OF THE ION EXCHANGE UNIT

Effect of Different Influent Salt Levels on Salt Removal

The unit was tested at different influent salt levels to determine the effect on sodium chloride removal. Runs were made with olive processing brines having sodium chloride levels of approximately 500, 1000, 2500 and 5000 ppm. During these runs sodium chloride concentration was the only variable held constant. A complete run comprises desalination, regeneration, and rinsing. Four composite samples were collected from each run and designated 1, 2, 3, and 4. These samples represented (1) composite influent to the unit, (2) composite effluent from the ion exchange unit (product), (3) composite regenerant influent, and (4) composite regenerant effluent.

The first salt level tested was approximately 600 ppm sodium chloride in the influent; this concentration was obtained by diluting olive processing water. During this series of runs the deionized effluent (product) and the regenerant influent were not filtered. Table III tabulates the results obtained from the analysis of composite samples collected.

These runs indicated that the sodium chloride content of olive processing water could be reduced from approximately 600 to 145 ppm. The amount of desalinated product obtained from each run was 30 to 140 gallons at a flow rate of 4 to 6 gpm. The same 150 gallons of regenerant were used for each run by recycling the effluent as influent for each successive regeneration. The color of the influent brine was light blue when the pH was relatively low, and reddish-brown when the pH was high. The final effluent was usually colorless, but a few samples had a yellow color. The color of the regenerant influent and effluent was brown.

The second salt level studied was approximately 1000 ppm as sodium chloride. Filtration was used to remove the insoluble organo-calcium compounds from the regenerant suspension and the solids from the product. The usual four samples were collected from the last run on each day of sampling by the NCA personnel. Table IV tabulates the results obtained by analysis of these samples. The salt content was reduced to a level

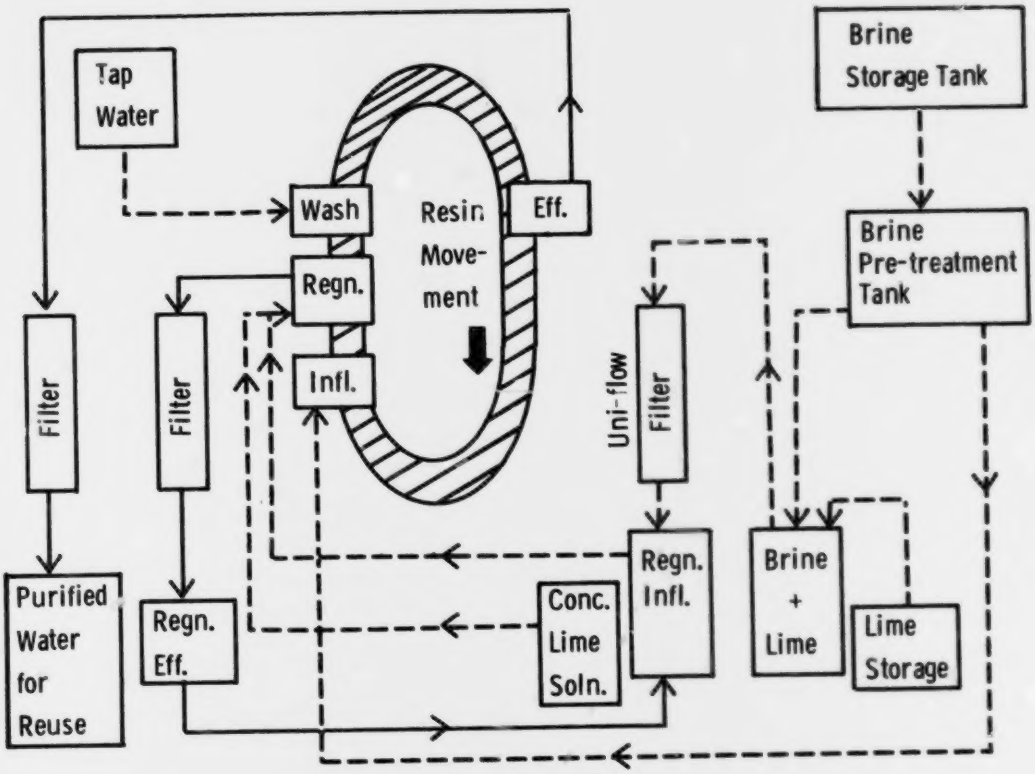


Figure 3. Flow Diagram of the Complete Ion Exchange and Regeneration Operation.

Table III

Analysis of Composite Samples Collected During the 600 ppm Salt Level Period

Run No.	Sample Number	pH	NaCl, ppm	SS, ppm	C. O. D., ppm
600-A*	1	7.4	610	9	154
	2	10.9	0	128	2
	3	11.6	610	29	85
	4	11.6	605	47	104
600-B	1	9.5	590	7	183
	2	11.4	113	113	101
	3	12.0	6370**	4244***	141
	4	12.1	6960**	5868***	134
600-C	1	11.0	600	14	158
	2	12.1	330	225	150
	3	11.8	630	852	161
	4	11.9	590	5956***	173

---

* A, B, and C are three different sets of samples collected on three different days. Samples represent the last run on each of these days.

** These unusually high values were due to residues of hydrochloric acid used to clean distributors.

*** These high values were due to suspended excess calcium hydroxide.

Table IV

Analysis of Composite Samples Collected During the 1000 ppm Salt Level Period

Run No.	Sample Number	pH	NaCl, ppm	SS, ppm	C.O.D., ppm
1000-A	1	10.6	1195	60	333
	2	11.5	190	3	115
	3	12.0	1180	30	340
	4	12.0	1117	150	290
1000-B	1	6.9	1190	2	356
	2	11.0	50	10	131
	3	12.0	1150	20	370
	4	12.0	1165	200	350
1000-C	1	6.8	1305	2	265
	2	12.0	90	0	86
	3	12.1	1340	0	214
	4	12.1	1320	10	187
1000-D	1	7.2	1195	16	N.R.*
	2	12.4	305	0	N.R.
	3	12.4	985	6	N.R.
	4	12.5	1095	9	N.R.
1000-E	1	7.4	1170	19	N.R.
	2	12.5	205	4	N.R.
	3	12.5	995	17	N.R.
	4	12.6	1070	11	N.R.

---

* N.R. = Not recorded.

of 168 ppm on the average in this series of runs. In batches 1000-B, -C, -D, and -E hydrochloric acid was added to the olive processing water to adjust the pH to about 7. The volume of desalinated product from an individual run was 45 to 70 gallons at a flow rate of 3 to 4.5 gpm. Regeneration was accomplished using recycling of the 150 gallons used for the run 1000-A.

Several runs were completed with a salt level of approximately 2700 ppm sodium chloride in the influent. The desalinated product averaged 155 ppm sodium chloride content as shown in Table V. The color of the influent brine was reddish-brown and the desalinated product was yellow. The regenerant influent and effluent were both yellow. The volume of product was 20 to 50 gallons at a flow rate of 3 to 4.5 gpm. Regeneration was accomplished by recycling 150 gallons of regenerant four times.

An influent brine of approximately 6000 ppm sodium chloride content was passed through the ion exchange unit as the fourth salt level to be tested. The results from analysis of eight groups of samples collected during this part of the project are tabulated in Table VI. The desalinated product had an average salinity of 790 ppm as sodium chloride. The volume of regenerant used for this series of runs was reduced to about 100 gallons per run and was recycled in sets of 3 or 4 runs.

Effect of pH on Sodium Chloride Removal

Under the experimental conditions used in this project, pH was found to have no significant influence on salt removal. This observation can be explained by the fact that the resin was in the calcium or hydroxyl form or, at times, in a carbonate form. When the influent olive processing water contacted the resin, the pH was increased to the alkaline side of 7 regardless of the influent pH level. Differences in performance due to pH changes would be expected if the resin bed had been fully converted to the sodium and chloride forms; no such condition was observed during the project.

Effect of Chemical Oxygen Demand Level on Salt Removal

No effect on salt removal would be expected from traces of non-polar organic compounds present in the influent brine. If neutral organic compounds were present in the influent in large amounts, they could coat the resin and decrease the salt removal efficiency. A more severe problem would exist if the organic compounds in the influent were polar in nature since they would compete for active sites on the resin with sodium and chloride ions. This competition would reduce the desalting efficiency of the resin bed. Neither extreme of these two situations was experienced in this project since the COD content of the influent did not exceed 1600 ppm. There was evidence that the salt removal was decreased as the COD of the influent increased, but this relationship was not rigorously established.

Table V

Analysis of Composite Samples Collected During the 2700 ppm Salt Level Period

Run No.	Sample Number	pH	NaCl, ppm	C. O. D. ppm	Ca, ppm	$CaCO_3$ ppm
2700-A	1	8.1	2500	1236	35	88
	2	12.4	295	735	766	1910
	3	12.4	1775	1093	470	1180
	4	12.4	1975	968	920	2290
2700-B	1	7.8	2750	359	24	59
	2	12.0	86	210	210	520
	3	12.3	2290	1258	660	1646
	4	12.4	2500	1176	870	2170
2700-C	1	7.6	2725	1367	24	59
	2	11.8	125	512	106	265
	3	12.3	2450	1367	412	1029
	4	12.4	2605	1179	884	2205
2700-D	1	8.2	2795	1333	12	29
	2	11.7	160	453	47	118
	3	12.5	2290	1201	590	1470
	4	12.5	2300	1101	719	1793
2700-E	1	8.0	2750	562	12	30
	2	11.8	130	320	51	130
	3	12.2	2390	485	283	706
	4	12.5	2400	440	1184	2950

Table VI

Analysis of Composite Samples Collected During the 6000 ppm Salt Level Period

Run No.	Sample Number	pH	NaCl, ppm	C. O. D., ppm	Ca, ppm	$CaCO_3$ ppm
6000-A	1	7.0	6810	1489	12	29
	2	11.9	490	234	318	794
	3	12.0	5700	1251	704	1705
	4	12.1	4650	1003	1072	2675
6000-B	1	7.3	6710	1510	12	29
	2	12.3	750	602	365	911
	3	12.4	5610	1219	754	1882
	4	12.5	5610	1111	1084	2705
6000-C	1	7.0	7050	1436	12	29
	2	11.9	850	266	236	590
	3	12.1	5720	1231	625	1560
	4	12.1	5250	1029	1108	2764
6000-D	1	7.1	5890	1143	18	44
	2	12.0	840	474	212	529
	3	12.2	5790	1209	660	1646
	4	12.2	5820	1067	2286	5703
6000-E	1	7.7	4950	1238	22	54
	2	11.2	1150	797	184	460
	3	11.7	2590	178	921	2299
	4	11.8	3010	257	1333	3327
6000-F	1	7.4	5590	1163	12	29
	2	11.7	490	176	212	529
	3	11.8	5420	1069	707	1764
	4	11.8	5310	930	1108	2764
6000-G	1	6.7	5290	969	12	29
	2	11.7	890	367	282	705
	3	11.7	5650	1014	695	1734
	4	11.8	4690	731	1120	2793
6000-H	1	6.9	5250	929	12	29
	2	11.9	840	346	212	529
	3	11.9	5720	927	577	1441
	4	12.0	3990	546	1025	2558

Work was completed on the establishment of a BOD/COD correlation factor for olive processing wastewater having sodium chloride levels of 2500 and 5000 ppm. A similar factor was established for the desalinated product water obtained from the ion exchange treatment of these brines. The data collected for the calculation of the correlation factors is tabulated in Table VII. The correlation factor varied with the salt content and the extent of treatment of the brine samples. The average value of the BOD/COD correlation factor was 0.35.

Effect of Ion Exchange Treatment of Olive Processing Waters on COD Level in Desalinated Product

The ion exchange treatment of olive processing water was expected to remove ionized and ionizable organic compounds. The detailed composition of olive processing water is not known, but such compounds as acetic acid, lactic acid, citric acid, saccharic acids, and hydrolyzed pectins are probably present. The Aqua-Ion technology would remove these compounds either by binding on the resin (to be released later during regeneration) or by formation of insoluble calcium salts (removed by filtration). Examination of the data tabulated in Tables III through VI indicates that substantial quantities of organic materials in the olive processing waters are removed during the ion exchange treatment. In some cases, as much as 85 percent of the initial COD material was removed by treatment and filtration. The effect of residual COD materials in the desalinated product water on the reuse potential is of importance, but was not evaluated in this project.

Effect of Different Salt Levels in Influent Brines on the Salt Removal at Constant COD and pH

Olive processing brines having an initial sodium chloride content of approximately 500, 1000, 2500, and 5000 ppm were passed through the ion exchange unit. Suspended solids were eliminated from consideration as a variable in this part of the study since the influent brine was filtered through a Uni-Flow filter before entering the ion exchange unit. Therefore, COD and influent pH were the only compositional factors which were adjusted to relatively constant values. The adjustment of the COD content was made by the addition of lactic acid to the olive brine until a value of about 800 ppm was reached. The pH was adjusted at about 7.5 by the addition of strong sodium hydroxide solution. One set of samples was collected and analyzed for each of the four salt levels; the results are tabulated in Table VIII. The salt removal was approximately the same until the salt level in the influent exceeded 2500 ppm.

Table VII

Correlation Factor Between Five Day B. O. D. and C. O. D. for Olive Processing Wastewaters

Wastewater				Desalinated Product		
NaCl, ppm	C. O. D., ppm	B. O. D., ppm	B. O. D. / C. O. D.	C. O. D., ppm	B. O. D., ppm	B. O. D. / C. O. D.
2500	560	200	0.36	290	130	0.45
"	760	320	0.42	340	120	0.35
"	700	290	0.41	330	110	0.33
"	660	260	0.39	320	120	0.37
"	630	230	0.37	370	130	0.35
"	610	270	0.44	310	150	0.48
	Average Value		0.40			0.39
5000	1490	470	0.32	230	70	0.30
"	1510	470	0.31	600	170	0.28
"	1440	360	0.25	270	70	0.26
"	1140	310	0.27	470	140	0.30
"	830	340	0.41	430	110	0.26
"	1160	480	0.41	180	70	0.39
"	970	230	0.24	370	100	0.27
"	930	260	0.28	350	90	0.26
	Average Value		0.31			0.29

Table VIII

Analysis of Composite Samples of Four Different Salt Levels with C. O. D. and pH Held Constant

Approx. Salt Level ppm	Sample Number	NaCl, ppm	C. O. D., ppm	pH	Ca ppm	$CaCO_3$ ppm
500	1	590	805	7.4	22	54
	2	190	212	10.6	44	108
	3	490	29	11.9	1323	3300
	4	1100	191	11.6	542	1352
1000	1	1070	958	7.5	22	54
	2	250	151	10.8	33	81
	3	1150	45	11.6	444	1109
	4	1350	146	11.8	737	1839
2500	1	2380	797	7.3	22	54
	2	210	465	10.7	44	108
	3	2410	91	11.7	2483	6194
	4	2450	137	11.6	750	1785
5000	1	5510	830	6.9	12	29
	2	1150	426	12.3	636	1587
	3	5150	1029	12.2	730	1823
	4	4650	816	12.3	2510	6262

Establishment of the Maximum Sodium Chloride Concentration Attainable in the Regenerant Effluent

The maximum sodium chloride concentration possible in the regeneration effluent is of considerable economic importance in evaluating the overall usefulness of ion exchange treatment of food processing brines. Ideally, both the product water and the concentrated regenerant solution could be recycled in selected stages of the food processing operation. If both of these objectives cannot be accomplished, concentrating the salt present in the treated processing water in a small volume would make further management less costly. To establish the maximum sodium chloride concentration attainable in the regenerant effluent, the liquid from each of a large number of resin regeneration runs was recycled after each individual run. To determine the increase in salt concentration in the regenerant effluent, a composite sample was taken from each effluent and the sodium chloride content was determined. The results of this investigation are tabulated in Table IX. The average increase in salt content in the regenerant effluent was approximately 40 percent (difference between original influent and lost effluent of a recycle series), depending on the salt level and the flow rate. It was found that the salt increase in the regenerant suspension occurs at a slow rate. There was not sufficient operating experience with any single influent brine composition to determine the maximum salt concentration attainable in the regenerant. A test was run using a concentration of approximately 20,000 ppm sodium chloride made by adding solid salt to an olive processing water. The use of this solution in regeneration gave an average increase in sodium chloride in the regenerant effluent of 595 ppm. This result indicated that it was possible to have substantial salt increases in the regenerant effluent even at salt levels of approximately 2 percent.

Effect of Cycle Time on Regeneration

The work on regeneration was continued using different cycle times. Table X tabulates the sodium chloride content of regenerant effluent and influent at various cycle times. The influent sodium chloride concentration was 1900 to 3500 ppm in these runs and the flow rate was 4.5 gpm. The regenerant effluent was recycled. The cycle times was calculated by dividing the gallons of influent used in a run by the flow rate of 4.5 gpm. The maximum average salt content increase was obtained with a cycle time of 30 minutes. The difference between the 10 and 20 minute cycle times was not significant.

Table IX

Increase in the Sodium Chloride Content of Regenerant Effluent as a Result of Regenerant Recycling

Run No.	Flow Rate, gpm	NaCl, ppm	
		INF	EFF
1 A	2	2070	2180
2 A		2300	2360
3 A		2480	2720
1 B	2	2410	2820
1 C	2	2590	2910
2 C		2600	2750
3 C		2660	2930
1 D	2	2540	2770
2 D		2630	2890
3 D		2670	3040
4 D		2710	3190
1 E	2	2760	3030
2 E		2790	3140
3 E		2860	3090
1 F	2	2940	3310
2 F		2910	3370
1 G	2	2920	3220
2 G		2970	3220
1 H	2	3030	3110
2 H		2970	2990
1 I	2	3000	3070
2 I		3050	3220
1 J	2	3070	3730
1 L	3	924	2451*
2 L		895	708
3 L		866	942
1 M	3	820	1106
2 M		1024	1103
1 R	6	1790	1856
2 R		1860	2086
3 R		1879	2106
4 R		1948	2131
5 R		1983	2135
1 T		2390	2516
2 T		2322	2434
3 T		2416	2486
4 T		2468	2490
1 U		2521	2633
2 U		2516	2785
3 U		2580	2668
4 U		2565	2673
1 S	7	2012	2173
2 S		2011	2112
3 S		2200	2280
4 S		2190	2311
1 O	8	1229	1280
2 O		1132	1252
3 O		1188	1451
4 O		1429	1633
1 Q	9	2416	2808
2 Q		2562	2890
3 Q		2896	2907
4 Q		2750	2867
1 K	3	20,534**	20,622
2 K		20,885	21,762
3 K		20,124	20,943

---

* High value due to cleaning of distributors with HCl.

** Salt content of the influent increased by adding NaCl.

Table X

The Sodium Chloride Content of the Regenerant Influent and Effluent at Various Cycle Times

Cycle Time, min.	NaCl, ppm INF	NaCl, ppm EFF	Cycle Time, min.	NaCl, ppm INF	NaCl, ppm EFF
10	1983	2135	40	2738	2849
	2318	2363		2738	2884
	2306	2451		2750	2890
				2770	2972
20	2516	2785		2785	2925
	2580	2668		2785	2984
	2565	2673		2790	2890
				2799	3177
30	2321	2790		2808	2907
	2594	2878		2828	2880
	2615	2837		2843	3024
	2650	2790		2858	3010
	2714	2937		3001	3060
	2732	2948		3352	3732
	2998	3179		3472	3674
	3033	3136			
	3117	3146			

Continuous Operation to Develop Treatment Cost Figures

In this phase of the study the time between the various unit operations, e.g. desalination, regeneration and rinsing was kept to a minimum. Only 20 to 30 seconds were required to pulse the resin between the runs. The only significant interruption was the time needed for fresh brine make-up. In preparation for continuous operation, the regeneration chamber was washed with a solution of hydrochloric acid to remove the organo-calcium compounds which had precipitated on the plastic beads holding the resin above the distributor screen. This treatment resulted in regenerant flow rates as high as 10 gpm. However, after a short time the flow rate decreased due to the plugging of the distributors by calcium carbonate and organo-calcium compounds. The sodium chloride content of the influent brine during this continuous operational period was 1000 to 1900 ppm and the flow rate was varied from 3.0 to 7.5 gpm. Table XI tabulates the reduction in sodium chloride content of the influent brine as the unit was operated continuously at different flow rates.

Table XI

Reduction in Salt Content of Influent Brine Obtained During the Continuous Operation of the Unit at Different Flow-Rates

Run No.	Flow Rate, gpm	INF NaCl, ppm	EFF Volume, gal.	NaCl, ppm
CA-1	4.5	1761	50	642
2	4.5		50	900
3	4.0		30	784
4	4.5		30	670
5	3.5		30	690
CB-1	4.5	1854	30	543
2	4.0		30	525
3	4.0		35	562
4	3.5		30	573
CC-1	4.5	1878	30	465
2	4.0		30	453
3	4.0		30	470
4	3.5		30	452
CD-1	3.5	1053	30	294
2	4.0		30	274
3	4.0		30	273
CE-1	5.0	1526	30	652
2	5.0		30	623
3	5.0		30	578
CF-1	5.0	1508	30	720
2	5.0		30	641
3	5.0		30	610
CG-1	7.5	1740	30	1211
2	7.0		30	1030
3	7.5		35	860
CH-1	7.0	1740	30	525
2	7.0		30	544
3	7.0		30	550
CI-1	7.5	1547	30	1508
2	7.0		30	1110
3	7.0		30	878

Hardness in Product Water from Ion Exchange Treated Brines

The use of calcium hydroxide as a regnerant in the Aqua-Ion technology causes this material to appear in the desalination product and results in a hard water of limited reuse potential without additional treatment. Calcium ions concentration was determined on a large number of the usual set of four samples collected from individual runs under a wide range of conditions. Table XII tabulates the calcium ion concentration and hardness as calcium carbonate for typical samples.

DISCUSSION

Salt Removal

In general, the salt removal obtained was satisfactory. The results demonstrated that desired product quality can be obtained at varying levels of polar solute concentration when COD and pH are relatively constant. At 5000 ppm sodium chloride concentration, the salt content of the product was higher than the target value of 175 ppm. The influent salt level was not believed to be the cause of the higher level of sodium

Table XII

Calcium Ion Concentration and Hardness of the Influent and Effluent of Both the Desalination and Regeneration Processes

Run Number	Sample Number*	Ca, ppm	Hardness as $CaCO_3$, ppm
H-A	1	33	83
	2	835	2083
	3	713	1778
	4	1091	2722
H-B	1	22	56
	2	668	1667
	3	701	1750
	4	935	2334
H-C	1	47	120
	2	800	2000
	3	870	1940
	4	990	2470

---

* Samples are the same as those in previous Tables.

chloride in the product water. Rather, the observed result could be attributed to intermixing which took place through the resin bed and caused displacement of the salt front. The intermixing problem was encountered during several periods of operation of the ion exchange unit. Near the end of the project a technique was found to minimize the intermixing in the resin bed. On completion of a regeneration cycle, valve No. 3 and an additional outlet valve (just prior to valve No. 2 of Figure 2) were opened. Compressed air was used to push out the regenerant effluent and the water filling the wash chamber. In this way, the contact between the regenerant and the final product at the top of the Higgins Loop was avoided. The quality of the final product was improved substantially when this procedure was applied. The salt content was reduced from 1500 ppm in the influent to a range of 130 to 270 ppm in the desalination product. The unit was operated at 4 gpm during this use of the revised procedure. It was unfortunate that more time was not available to study all the variables examined and reported above which were obtained under less than optimal operating conditions.

Conventional Regeneration

Slaked lime ($Ca(OH)_2$) performed successfully to regenerate spent resin used to desalinate the olive processing brines. The recycling of the regenerant effluent increased the sodium chloride content of the regenerant. The long-term trend of sodium chloride increase was apparent from examination of data in Table IX, although the difference in salt content in any pair of adjacent runs did not appear to be significant (for example Run No. 1C and Run No. 3C). This was due to the diluting effect of the wash water filling the void space of the resin. The void space can represent as much as 40 percent of the total volume of the resin.

At high flow rates, when distributors tended to plug up, washing with acid solution was required to open up the flow channels. The residues of hydrochloric acid solution resulted in sudden increases in the chloride ion readings for some effluent samples. The preliming and filtration of the regnerant influent resulted in shorter regneration times and longer operational periods with fewer acid washings being required.

Within the time limit assigned to any given phase of the project, the average increase in the sodium chloride concentration of the regenerant solution was approximately 40 percent. There was no indication of a leveling off of the rate of sodium chloride increase in the regenerant effluent with increasing number of cycles.

The best regeneration cycle time was found to be 30 minutes.

Carbonate Regeneration

One of the reasons that higher than expected sodium chloride levels were observed in certain runs was because the resin was in a calcium carbonate form rather than a calcium hydroxide form.

The equations for the reaction involved in carbonate regeneration are the following:

$$\text{(Cation)}\quad R_2Ca + 2\,NaCl \longrightarrow 2\,RNa + CaCl_2$$

$$\text{(Anion)}\quad R_2CO_3 + CaCl_2 \longrightarrow 2\,RCl + CaCO_3$$

It was observed that salt removal was only about 50 percent of the level removed when the resin was in the calcium hydroxide form in those runs where the resin was partially or completely in the carbonate form. The relatively low calcium content of the desalinated product in these runs confirmed the carbonate resin mode. The low calcium content of desalinated product effluent shown in Table XIII was the result of removing most of the calcium as calcium carbonate. The sludge formed from the filtration of the desalinated product water was found to contain substantial amounts of calcium carbonate.

Table XIII

The Effect of the Carbonate Regeneration on the Calcium Content of the Product Water

Run No.	INF*			EFF		
	NaCl	Ca	$CaCO_3$	NaCl	Ca	$CaCO_3$
CO3 A	1590	43	108	690	54	135
CO3 B	2850	12	29	1190	71	176
CO3 C	2950	12	29	1290	47	118
CO3 D	1050	24	59	430	6	15
CO3 E	1150	24	59	570	12	29
CO3 F	1980	35	88	590	47	118
CO3 G	1650	33	81	590	43	108

---

* All results are in ppm.

The introduction of carbon dioxide into the ion exchange system is the reason for the appearance of carbonate regeneration. The carbon dioxide could have been introduced at the following points:

a. In the compressed air used to move the resin. If this were the source, it could be corrected by passing the air through an alkaline solution before compression.

b. In the lime used for the preparation of the regenerant influent. Samples of lime were found to contain large quantities of calcium carbonate. This could be corrected by storing the lime in tightly closed containers.

c. In gas transfer through the cloth of uncovered filter hoses. The plastic wrapping of the filter hose was occasionally torn by strong winds; a combination of low temperatures and rain wetting the hoses could promote the uptake of atmospheric carbon dioxide.

The problem of carbonate regeneration could be eliminated by operating the unit at slower rates or by employing a larger desalination leg. The second change would be the most economic way to correct for the possibility of carbonate regeneration in a scaled up production unit.

The filtration of the regenerant and the desalinated product was not possible in a few runs due to the oxidative degradation of the cotton filter hoses. The perforation of the Uni-Flow filters on these occasions was the reason for the high suspended solids content of some samples and for the very high values for calcium and suspended solids in certain of the regenerant suspensions. The perforation of filter hoses can be forestalled by good maintenance; hoses should be replaced near the end of their expected service life.

CONCLUSIONS

The desired quality of the desalination product was obtained under most operating conditions. Under certain conditions, the sodium chloride content would be considered high. However, in some areas of California the total dissolved solids content of municipal water supply range from 410 to 1,243 ppm (Anon., 1962).

The desalinated product is a hard water and its calcium content should be reduced in order to increase reuse options.

The sodium chloride content of recycled regenerant solutions was increased 40 percent over the influent brine level and evidence was obtained that a 10 fold increase was possible. Stated in another way, the sodium chloride present in the original olive processing water was potentially concentrated in one-tenth of the original volume. At the same time a volume of desalinated water equal to the volume of the treated olive processing brine was produced for possible reuse.

The cost of desalting 1000 gallons of olive processing brine was estimated at $0.26. The estimate was based on extrapolation of data from the pilot plant operation. The flow rate used in the estimate was 4 gpm which corresponds to a flow rate of 5.1 gpm/sq ft of resin bed.

REFERENCES

1. Anon. 1962. California Domestic Water Supplies, State of California, Department of Public Health.

2. Etchells, J. L., R. N. Costilow, T. E. Anderson, and T. A. Bell. 1964. Pure Culture Fermentation of Brined Cucumbers. Applied Microbiology 12(6), 523-535.

3. Etchells, J. L., A. F. Berg, I. D. Kittel, T. A. Bell, and H. P. Fleming. 1966. Pure Culture Fermentation of Green Olives. Applied Microbiology 14(6), 1027-1041.

4. Lowe, E. and E. L. Durkee. 1971. Salt Reclamation from Food Processing Brines Using Submerged Combustion. Proceedings of the Second National Symposium on Food Processing Wastes, Denver, Colorado, March 23.

5. Heid, J. L. and M. A. Joslyn. 1967. Fundamentals of Food Processing Operations, Chapter 4 (by M. A. Joslyn and A. Timmons), page 79, AVI Publishing Co., Inc., Westport, Connecticut.

6. Mercer, W. A., H. J. Maagdenberg, and J. W. Ralls. 1970. Reconditioning and Reuse of Food Processing Brines, Proceedings of the First National Symposium on Food Processing Wastes, Portland, Oregon, pp. 281-293.

7. Popper, K. 1970. Possible Uses of Uni-Flow Filters, Proceedings of the First National Symposium on Food Processing Wastes, Portland, Oregon, pp. 362-376.

8. Vaughn, R. H., M. H. Martin, K. E. Stevenson, M. C. Johnson, and V. M. Crampton. 1969. Salt-Free Storage of Olives and Other Produce for Future Processing. Food Tech. 23(6), 832-834.

PRODUCTION AND DISPOSAL PRACTICES FOR LIQUID WASTES FROM CANNERY AND FREEZING FRUITS AND VEGETABLES

by

Walter W. Rose*, Walter A. Mercer*, Allen Katsuyama*,
Richard W. Sternberg**, Glen V. Brauner**, Norman A. Olson*,
and Dr. Kenneth G. Weckel***

INTRODUCTION

The food processing industry must conform to provisions of a number of federal and state laws and regulations to protect the environment from various forms of degradation and pollution. The Refuse Act of 1899 requires a permit for disposal of refuse in a liquid state into any navigable water or its tributaries in the United States. The Air Quality Act of 1965 and the Clean Air Amendments of 1970 cover air pollution and control. These legislations, collectively referred to as the Clean Air Act, include not only emissions from industrial stacks, but undesirable odors and air pollution from exhausts of autos. The Water Quality Act of 1965 provides for the establishment of standards by states for water quality. The Clean Water Restoration Act of 1966 provides for grants to jurisdictions for development of improved methods of waste treatment, water purification, sewer design, and construction of waste treatment plants. The Water Quality Improvement Act of 1970 implements protection against pollution, particularly by oil and hazardous materials, and marine sanitation. The Solid Waste Disposal Act of 1965 authorized a development for economic disposal of solid waste including trash, garbage, paper, and scrap metal. In addition, definitive regulations have been established in a number of states on some or all of these subjects. The operations of all fruit and vegetable process plants are subject to these acts and regulations.

The effective minimizing of the pollutional loads developed in fruit and vegetable processing is important to both the economic and social status of the enterprise. It is the objective of this report to consolidate and make available the substance of published information dealing with wastes from fruit and vegetable processing (excluding potatoes). This information will be used to direct attention to potentials in reducing pollution loads through research. Much of such research will have economic advantages to the operation, and will enable the processors to meet the objectives of environmental protection programs.

---

*Western Research Laboratory, National Canners Association, Berkeley, California.

**Washington Research Laboratory, National Canners Association, Washington, D.C.

***Department of Food Science and Industries, University of Wisconsin, Madison, Wisconsin.

Waste Quantities

The fruit and vegetable canning and freezing industry includes operations in 1,838 plants employing 167,000 persons, resulting in increased value to the raw crop of some $2.2 billion. This industry utilizes an estimated 99 billion gallons of intake water, recirculates about 64 percent of the intake volume and discharges about 96 billion gallons (see other estimates below). The percentages of these values compared to those for all U.S. manufacturing and for all food and kindred products are, respectively:

Number of Plants, 0.6 and 5.6 percent

Number of Employees, 0.9 and 10.1 percent

Value Added, 0.8 and 8.3 percent

Intake Water, 0.6 and 12.2 percent

Recirculated Water, 0.3 and 12.4 percent

Discharge Water, 0.7 and 12.8 percent

All of the figures are from preliminary reports of the 1967 Census of Manufacturers, U.S. Department of Commerce, issued in 1970. An independent estimate of the quantity of water discharged in canning and freezing fruits and vegetables made for this study is somewhat lower than the census value: 80 billion gallons, including a very small quanitity used in dehydration plants and a substantial quantity used in types of manufacturing excluded from the census figures. The independent estimates are in Table 1.

Table 1 also gives estimates of raw product tonnages, and of BOD, suspended solids, and solid residuals generated. "Other fruit" and "Other vegetables", includes all those not specifically listed. Estimated totals, for the United States for a recent year, mostly 1968, are:

26.4 million tons of raw product

80 billion gallons of wastewater discharged

760 million pounds of BOD generated

360 million pounds of SS generated

8.9 million tons of solid residuals

Citrus, tomatoes, corn and white potatoes (excluding dehydrated potatoes) account for 67 percent of the raw tonnage, 61 percent of the waste water, 45 percent of the BOD, 61 percent of the suspended solids, and 71 percent of the solid residuals.

The raw tonnage estimates are believed to be the most precise. They are mostly from the U.S. Department of Agriculture Crop Reporting Service, but

TABLE I

Wastes From Canned and Frozen Fruits and Vegetables

	Raw Tons	Waste Water		BOD		Susp. Solids		Solid Residuals	
	1,000 tons	10^3 gal/ ton	mil. gal.	lbs/ ton	mil. lbs.	lbs./ ton	mil. lbs.	lbs./ ton	1,000 tons
apple	1,000	5.0	5,000	40	40	5	5	600	320
apricot	120	5.0	600	60	7	12	1	360	21
cherry	190	2.0	400	20	4	6	1	300	27
citrus	7,800	3.0	23,000	4	31	7	55	880	3,390
peach	1,100	4.0	4,400	60	66	10	11	500	270
pears	400	4.0	1,600	70	28	20	8	660	120
pineapple	1,000	.5	500	20	20	8	8	900	450
other fruit	400	8.0	3,200	20	8	10	4	---	80
Sub-Total	12,250		38,700		200		90		4,680
asparagus	120	10.0	1,200	10	1	7	1	720	45
beans, lima	120	9.0	1,100	25	3	80	10	280	16
beans, snap	630	4.5	2,800	30	19	4	3	420	130
beets	270	4.0	1,100	150	40	50	14	820	110
carrots	280	4.0	1,100	55	15	40	11	960	150
corn	2,500	1.8	4,500	25	62	10	25	1,340	1,060
peas	580	5.0	2,900	50	29	10	6	260	78
pump., squ.	220	3.0	700	80	18	15	3	1,240	150
sauerkraut	230	.5	100	15	3	3	1	640	75
spinach, gr.	240	9.0	2,200	25	6	10	2	320	37
sw. potato	150	7.0	1,000	200	30	80	12	(in other veg.)	
tomato	5,000	2.0	10,000	12	60	4	20	200	400
other veg.	1,300	4.0	5,200	60	80	30	40	--	500
Sub-Total	11,700		34,000		370		150		3,350
Total Above	24,000		73,000		570		240		8,030
white potato	2,400	4.0	9,600	80	190	50	120	760	910
TOTAL	26,400		82,000		760		360		8,940

some are National Canners Association estimates based on canned and frozen pack statistics. They are for 1968 except that tomato tonnage was reduced from 7 million to 5 million tons because 1967 was abnormally high for canning tomatoes processed. The other estimates are based on averages of widely varying figures per ton, mostly published in the 1960's, but some earlier; a few of the sources are unpublished data of the National Canners Association. The varying estimates for a given product are partly the result of real plant to plant differences. Data from many of the references were converted from values per case to values per ton using U.S. Department of Agriculture figures for average cases per ton. Some BOD data were estimated from COD Figures. Missing data, in particular those for "other fruit", and "other vegetables" were estimated by comparison with data for the principal products. The second digit in most numbers in the table is highly questionable and the first digit is generally insecure.

A 1969 report by, Secretary of Agriculture and Director of the Office of Science and Technology, gave the following estimates for canning and freezing fruits and vegetables:

> 1963 Estimate: 71 billion gallons wastewater; 660 million pounds BOD
>
> 1972 Projection: 93.5 billion gallons wastewater; 845 pounds BOD

Powers, et al. (1967) estimated that 87 billion gallons of water were discharged from canned and frozen fruits and vegetables in 1964; and for 1963 the same quantity of wastewater and also 1,190 million pounds of BOD and 600 million pounds of suspended solids generated from all canned and frozen foods. These figures are somewhat higher than the current study estimates and the additional products included in the earlier estimates do not seem to account for the differences in BOD and SS.

Other estimates derived from Powers, et al. (1967) indicate that in 1963 all food and kindred products manufacturing was about 1/10 and the canned and frozen fruits and vegetables industry was about 1/100 of all U.S. manufacturing as measured by value added. These two segments of the economy used about 5.4 and .5 percent, respectively, of the total water, but produced about 20 percent and 5 percent, respectively, of the total BOD. These comparisons reflect the relatively high strength wastewater discharged by food manufacturing.

The U.S. Department of Interior, FWPCA, publication, Industrial Waste Profiles, No. 6. (1967) estimated for canned and frozen fruits and vegetables the following total waste loads, million pounds:

Year	1963	1968	1972	1977
BOD	660	785	845	905
SS	750	890	960	1035
TDS	710	845	910	980

Estimates were made for the current survey of total solids in the wastewater generated by the industry. They were based on sparser data than were available for the other items and are, therefore, not listed in detail. The estimated total was 2.4 billion pounds of total solids, a very high proportion coming from potato processing.

Effluent Treatment

All of the figures on wastes referred to above pertain to generated wastes. Large proportions are reduced by treatment before final discharge.

The 1963 Census of Manufacturers is the source of the following totals and percentages of wastewater flows from plants reporting 20 million gallons per year or more:

		Percent To:		
	Total Flow, Billion Gallons	Public Treatment	Ground	Surface Water
All U.S. Manufacturing	13,200	7	1+	90
Food and Kindred Products	688	35	11	51
Canned and Frozen Fruits & Vegetables	66	38	17	42

The small quantities unaccounted for are transferred to other uses. The food industries discharged much higher proportions of their liquid wastes to public sewers and to ground than did manufacturers as a whole. The degree of purification at public treatment plants varies widely; estimates of their average removals from the U.S. Department of Interior, FWPCA publication, Industrial Waste Profiles, No. 6. (1967) reports: 75 percent of the BOD, 85 percent of the SS and 14 percent of the TDS. Discharges to ground are principally by irrigation, mostly spray irrigation, but also by seepage from ponds and by pumping into non-productive wells. Ground disposal generally removes very high percentages of the pollutional load. The high degree of utilization of public plants and ground discharge by food processors is partly explained by the need for reducing the relatively high strength of their wastes.

Most industrial wastewater (including that from food processing) is used for cooling or for other relatively non-contaminating purposes. Added heat may be a problem, but not other types of pollution. Discharging this more or less clean water to surface water is necessary to maintain stream flows and provide water for down-stream populations and industries. Wastewater disposed of in streams and lakes is often treated before discharge.

A 1965 study by Bower found the following distribution of liquid wastes disposal practices in 80 fruit and vegetable canneries, some of which were also freezers:

Discharge To:	Percent of Plants: Urban	Non-Urban	Total
City Systems	100	9	47
Ponds	0	28	16
Spray Irrigation	0	55	31
Surface Water	0	9	5

Urban plants were defined as those located within cities; non-urban plants, those located in the country, in small towns or on the outskirts of cities. The contrast in disposal methods by the two groups reflects the availability of treatment plants in cities and the high cost of city land.

Table II, mostly 1969 - 1970 data from a preliminary summary of a solid waste survey of canning and freezing by the National Canners Association shows the distribution of liquid waste disposal methods found in a study of all canned and frozen fruits and vegetables except pineapple. The same plant might use more than one of the listed methods; i.e., a plant putting up more than one product was tallied under each of them. "Holding" and "treatment" ponds were not strictly defined; generally the removal of pollution would be less in a holding than in a treatment pond. Some methods of treatment at the plant or of disposal were not included in the summary. For example, about half the citrus plants used additional methods, and the clarifiers which remove settleable material at most potato plants were omitted. Most reliance on city systems was by tomato, peach, pear, and miscellaneous fruit plants; on treatment ponds by potato and apple plants; and on irrigation, by corn, apple and pea plants.

TABLE II

	Percent of Plants Using:			
Product	City Systems	Holding Ponds	Treatment Ponds	Irrigation
Citrus	12	--*	10	24
Tomato	67	11	19	13
Corn	40	12	28	44
Potato	43	14	57	21
Peach	83	3	11	11
Apple	30	10	40	30
Snapbean	58	6	24	27
Pea	39	13	10	36
Pear	92	4	8	8
Other Fruit	67	10	16	20
Other Vegetables	59	10	23	17

*combined percentage for holding and treatment ponds is 10.

Industry Waste Costs

Preliminary data from the National Canners Association Solid Waste Survey, supplemented by information from Bower (1965), Boyle, et al. (1968), U.S. Department of Interior, FWPCA (1970), National Canners Association (1959), and the U.S. Dept. of Interior, FWPCA (1969), are the basis of the following estimated expenditures for an assumed average fruit and vegetable processing plant:

Cost Data, Liquid Waste

Item	Item Cost $ Capital	Item Cost $ O&M	Percentage of plants
In-plant	$14,000	1,000	100
Simple treatment (1)	12,000	4,000	7
Further treatment (2)	44,000	13,000	20
Irrigation	24,000	4,500	20
City treatment	---	6,000	56

(1) Simple treatment includes holding ponds, primary treatment, etc.
(2) Further treatment includes aerated lagoons, secondary treatment, etc.

The characteristics of an "average" plant were estimated from data on apple, peach, pear, snapbean, corn, pea and tomato processing. The following plant size and waste averages were assumed: 15,000 tons of raw product in a 100 day season; 3,000 gal./ton, or about 450,000 gpd, or 45 million gal./year; 30 lbs./ton of BOD, approximating 1,000 ppm BOD; 10 lbs./ton of SS, approximating 400 ppm. Component costs from the cited references were estimated for a plant with these "average" characteristics; they were converted to 1970 dollars using data in U.S. Department of Interior, FWPCA, 1970. Some estimates were averages of figures that varied over a wide range.

"In-plant" includes waste flumes, piping, pumps, tanks, sumps, gutters and screens. Primary and secondary treatment systems were not well or consistently defined in the references.

Using unit costs per year (and the assumed BOD removals given in the following table) overall costs for different treatment efficiencies were estimated for an "average" plant; the in-plant costs were added to each of the other systems' costs (figures rounded):

Treatment	BOD, Percent Removed	Cost Per Year
In-Plant	5	$ 2,400
Primary	50	7,600
Secondary	80	19,000
Irrigation	100	9,300
City treatment	75	8,400

Suspended solids would be removed in higher percentages than BOD by the simpler systems.

Estimates derived from figures in a report by The California State Water Resources Control Board, Publication No. 39. (1968), for a .5 mgd plant are as follows (converted to 1970 costs and rounded):

Item	BOD percent Removed	Cost Per Year Capital	 O&M
In-Plant	0-10	$1,200	5,000
Sedimentation	10	4,200	7,500
Aerobic Pond	50	4,700	9,000
Aerated Lagoon	80	8,700	11,000
Irrigation	100	4,000	12,000

In-plant costs included those for screening and for handling solid wastes; these in-plant costs were estimated to be required in all plants and have been added to the costs of the other systems.

Waste Problems

While the figures in the foregoing seem to indicate that the water usage and pollution loads from fruit and vegetable process operations are but a small part of the total national industrial usage and load, the significance is actually considerably greater. During the past 20 years, there has been a constant consolidation of smaller operations into larger more centralized process operations, resulting in greater usage of water and more discharge of wastes per operation. Thus, during the highly seasonal periods of operation in the industry it is not unusual for a process operation to utilize much more water and to generate more waste than the community in which the operation is located. The pollution load from a plant may be 200 - 300 times that in the community of 500 - 1,000 persons in which the plant is located; or the food waste may be equivalent to twice that of the wastes of a city of 50,000 in which the plant is located. Thus, the quantities of the solid wastes, which may be 7 - 70 tons per 10 thousand cases of product, or of the pollutional load in the process effluent involve treatment processes of considerable magnitude involving large capital and operational expenses. Of significance is that the waste loads in this industry are generated within a relatively small harvest period in the year, and consequently treatment systems must be geared to prevent pollution of outlets at periods when rainfall and flow are at their minima. Further, where the wastes are channeled into municipal systems, often these are already overtaxed in capacity and inadequate for the community requirements.

The solid wastes produced in processing many fruits and vegetables have relatively little economic value and are not marketable. Disposal sometimes consists of distribution to farmers in the immediate area of the plant who incorporate it as part of the feed for cattle, swine, or poultry, or disperse it upon the land. However, "waste" material from some of the products with the largest quantities of solid residuals are specifically handled for stock feed. Examples are citrus, corn, and potatoes, all three produced in large tonnages for processing and in areas where cattle or other stock are available for feeding. The National Canners Association 1970 Solid Waste Survey indicated that as a result of this use of these three products, about three-fourths of all residuals from fruit and vegetable processing are used as by-products. Solid wastes may range from 5 to 70 percent of the raw harvested crop and their handling and disposal create pollution and hygiene problems.

Technological Changes in Food Processing

Several persons active in food processing research, engineering and teaching were asked to predict changes in the technology in the next several years and the effects of the changes on wastes and pollution. All types of pollution (solid, liquid and air) were to be included in the predictions. All of the experts responded. They expected changes in all of the 23 agricultural, harvesting, transporting, processing and waste handling steps that were specifically listed in the query, and they generally expected the changes to improve the waste and pollution situation. A summary of specific comments follows:

Agriculture: New varieties should permit better utilization and, therefore, less waste. One expert suggested a gain of 1 percent; another a gain of 50 percent. Some thought new varieties would not effect wastes. About half the experts believe fertilizer applications and irrigation will be better controlled with less waste and pollution, a few anticipated worse effects from increased applications. Most thought that pesticide pollution would be decreased by improved materials and methods and by better controls. Increased use of other chemicals was expected to increase problems by two respondents, but a majority expected no change or an improvement.

Harvest and Transport: Opinions were divided on the effects of increased mechanical harvest; sorting in the field and once-over harvesting could reduce problems, but more soil and trash could increase them. Similarly, changes in containers and transportation might improve or worsen the problems, although overall they were expected to be improved. Most cited bulk handling or hauling in water; some expected more and some less product damage, a factor likely to vary with the product and the hauling method. Most thought that increased sorting and pulping in the field would alleviate waste problems, but one expert said less control could be exercised there.

Processing: Nearly all of the many cited examples of changes in in-plant equipment and methods were expected to reduce waste and pollution. There was a small minority pessimistic about product packaging, including a suggestion of increased specialized packaging, but some thought more functional, more reusable or more destructible packages would come into use. Listed in-plant improvements included: less water usage, more water recirculation, more efficient washing, improved blanching and peeling methods, product transportation methods using no or less water, and more efficient product utilization. The experts expected changes in quality standards and split on whether they would increase or decrease waste and pollution.

Waste Handling: Improvements in this field were anticipated by nearly all the experts. Cited here were better solid-liquid separation methods, improved or more widely used liquid waste treatment, and the development of more by-products, although one thought the last unlikely. Most expected better solid waste disposal methods, but one person was pessimistic about this. Pollution regulations were expected to be stricter.

DISCUSSION

Characterization of Wastes

The processing of fruits and vegetables, i.e., the conversion of the raw form into a processed (canned or frozen) form for use at some future time and other place, involves application of many treatments In the processing some losses of organic and inorganic material occur, including separation of soil and extraneous material, peel, seed, core, cob, fiber, fines, spillage and solubles. These wastes are collected as discrete materials and liquid effluent, the latter containing colloidal, suspended, discrete and soluble solids.

The discrete wastes are generally removed physically; the pollution load of the liquid effluent is dependent upon the concentrations of various components. The capability of reducing the pollution load in the effluent depends largely on knowing the point of origin of the wastes generated during processing, the causes for their occurrence, and their magnitude and characterization. With such information, means to correct malfunction or unsatisfactory operation may be applied, or efforts made to develop alternate systems which minimize the loss of extracted solids or leachate. More importantly, efforts toward reduction in pollution load can be directed to those phases of operation where generation of pollution load is relatively great. Complementary to identifying the important sources of pollution load in the effluent is the application of monitoring systems by which these operations can be better defined.

Relatively few studies have been made on the magnitude and characterization of the wastes generated during processing; these include studies on apples, citrus, peach, pear, beets, carrots, corn, peas, snapbeans and tomatoes. Additional information is needed on the characterization of the wastes developed in processing these crops and others. Examples of the potential benefits of such studies have been the development of fruit peelers which are more efficient in separation of peel and skin with less loss of solubles (apple, pear, tomato and vegetable peeler, beet, carrot and potato); characterization of the losses of suspended and soluble materials during water blanching; improved container fillers; and isolation of waste streams for conditioning and reuse. Efforts in the characterization of in-plant wastes should be greatly intensified, so that alternate processes may be developed. The concentration of pollution loads in effluents from water blanchers makes urgent the development and application of other systems of blanching in which there is less loss of solids and conservation of product.

Water Conservation

A major problem in the conservation of water in many food process operations is that it is considered the cheapest commodity available, and hence, more readily expendable in comparison with investment in sophisticated equipment and in labor. Efforts to encourage conservation of water have not been wholly successful except where it is critical in supply or where economies are apparent in its conservation.

The conservation of water in processing fruits and vegetables is important for several reasons; the volume of water used is directly related to volume of effluent discharged, which in turn is directly related to capital and treatment costs for the effluent; water is a vector and extractant for solubles and suspended solids, either from useable product or waste product; it is a vector for heat, which is relatively costly; and finally, it is costly per se, contrary to the popular evaluation that it is not.

Little data are available on the costs of water used in the processing of fruits and vegetables, including not only the power and capital costs in making it available from wells, but also the costs of its distribution through the factory and of its ultimate treatment; little information is available on the leaching effects resulting in greater pollution loads from the excessive uses of water.

Studies should be undertaken to establish norms in the use of water for processing various fruit and vegetable products to establish means of conservation where such will be effective in reducing pollution loads, and to develop better understanding by management of costs of water.

Among subjects in need of study are the following:

1. Develop quantitative data on the loss of soil with various root crops during mechanical harvesting with the objective of focusing attention on the magnitude of the problem and the necessity for engineering improvement in harvest machinery. (Mercer, 1967).

2. Develop experimental data on new concepts for field site wash stations to remove and recover soil from root and other crops, and on the related transport costs and crop quality. (Mercer, 1967).

3. Develop quantitative data on water usage and costs, including energy and capital costs in water procurement and in its conveyance throughout the plant.

4. Develop energy balances in water usage throughout the processes, including water transport, to evaluate better the costs of water uses.

5. Develop data on the costs of waste effluent disposal in terms of actual (uncontrolled) water usage and conservative (controlled) water usage.

6. Develop experimental data on new concepts for cleaning raw product, including soak and hydraulic systems, cavitation, detergent wash, air stream separation, mechanical abrasion, and osmotically balanced washing. (Holmquist et. al., 1954; and Gould, et al., 1959).

7. Develop improved and new procedures for treating water to permit greater multiple use for fruit and vegetable processes, and particularly to compare economic values in the use of fresh and treated water.

In this review consideration has been given to the use of water in procurement, transfer and processing of fruits and vegetables. There are many possible ideas for improvement in the procedures used. Perhaps the greatest need is for solid factual information that will show:

1. The nature and magnitude of each of the problems.

2. What the economic advantages would be from employment of improved, feasible procedures for conservation of water in the total process.

These are collective and interrelated problems. The voluntary employment of the conservation procedures can best be implemented by establishing economic benefits. Regulatory action, likely, is not feasible without such information. The current emphasis on pollution control has stimulated interest by processors in water conservation. It has given impetus to manufacturers to make improvements in equipment and in the application of water in fruit and vegetable procurement and processing. This interest on the part of food processors in water conservation needs to be supported by a document which describes the economic benefits of changing water use practices in food plants.

In principal, there are several major areas in which research should be done to achieve these aims:

1. Establish research to determine the feasibility of use of water at site of harvest to:

   A. Pre-wash the crop on the site.

   B. Conserve the soil.

   C. Reduce transport of non-edible material.

   D. Facilitate transport of crop from field to plant.

   E. Establish economic data on these potentials.

2. Undertake research on water reuse and water recovery, with major emphasis on the economic implications of water conservation and recovery in the broadest perspective.

Reconditioning Water for Reuse

In addition to conservation of water in processing fruits and vegetables, there is developing a great need for reconditioning and reuse of water for certain phases of the operations. This need is the result of decreasing availability of water and changes in water quality. A limited number of studies have been conducted, principally in processing of tomatoes, indicating feasibility in the reuse or recycling of water in certain steps of the processes. Clean and sterile retort water, for example, may be directed upstream; product rinse water may be directed upstream to product washing treatments. A number of procedures are available for reconditioning water: ion exchange, reverse osmosis, filtration, sedimentation, flocculation, and centrifugation. These have been given relatively little application to reconditioning water for reuse in fruit and vegetable processing primarily because water generally is readily available and because the costs of water in processing are not known. In some instances, however, the supply of water is already critical and reuse is essential.

Application has been made in conditioning water for use because its quality is unacceptable as a medium for foods; conditioning has been employed to correct effluent waste otherwise unacceptable as waste. The potentials of reconditioning water, however, have not been adequately determined in order to more effectively stress potentials in conservation. Studies are needed on the application of various systems of treatment of water from various in-process streams and on the determination of their efficacy and economic status. Evaluation must be made also of the hygienic acceptability of the conditioned waters, since this is an important criterion for foods. These studies will further direct attention to means for conserving water.

Blanching

The blanching of vegetables (and some fruits) is done to achieve certain properties considered essential for canning, freezing and drying. A major portion of the vegetable crop is blanched in water; the balance in steam. The blanching process has three significant effects on operations: It generates a significant pollution load; it causes losses of nutrients; it causes reductions in yield. These are of considerable economic importance. The processes used for blanching have not been adequately investigated to permit maximum correction of the adverse effects. It is apparent that suitable determinative end points are not available to permit application of only the necessary degrees of blanching (excessive blanching appears to be the rule), and possible alternative systems have not been adequately investigated. Among these may be cited the sequential timing of liquid and liquid/steam thermal processes; use of osmotically balanced blanching media, hot air, infra-red, micro-wave; and sequences of these procedures. The processes should be updated for crops now harvested, transported and handled by the more rapid mechanical procedures.

The relatively low volumes of effluents from water or steam blanching procedures have high concentrations of pollution load. These effluents are separable from the total waste stream and can be subjected to treatments such as concentration and drying or removal otherwise, thereby reducing significantly pollution loads in the total process waste flow.

Studies are needed to correct the overall impact of blanching on pollution loads in vegetable operations and to establish potential operational parameters in this process.

Solid Wastes

The removal of peel from fruits and skins from root crops creates significant organic loads in the effluent streams. The discrete portions of these wastes are separable and removable. The usual procedures of separation follow thermal pre-treatments, which result in high concentrations of solubles or suspended material in the effluents.

Use of peel waste has been achieved to some extent; for example, in citrus, pineapple and apple waste. For many peel wastes, however, there appears to be no market, and their disposal is an operational burden. At least two phases of research are needed to reduce the pollution loads involved in peeling fruit and vegetable products. The first is investigation and development of alternate systems of solid waste separation to reduce concurrent losses in solubles and suspended solids and to increase product recovery. The second is to characterize and evaluate the material for recovery of potentially useful materials or applications. The wastes generally are sources of leachate adding to pollution loads and creating hygiene problems. Traditional procedures of disposal of the separated wastes include use as feed for animal or fowl and on land. The possible utilization of these wastes has not been given adequate consideration in the light of modern food process operations. There are techniques of conversion of the wastes into alternate physical forms for use or disposal; there are potential extractants that may have market value; there are potential markets for nutrients, chemicals or fertilizers. There is potential in the consolidation of wastes from adjacent processing plants for economics in conversion and marketing. The quantities of such wastes can be extensive, ranging from 5 to 70 percent of the raw product, and add significant stress to operations and to pollution control.

The recently developed dry caustic peeling of certain root crops appears to have benefits in minimizing the problem of solid wastes, and the concept should be extended. Other procedures, including comminution, concentration and incineration should be evaluated to provide better disposal systems and reduce pollution loads in effluents.

Because the soil and peel loads in certain crops are large, consideration should be given to in-field washing and peeling during harvest; this would retain both soil and organic peel materials on the land. Although there appears to be objection to such concepts on hygiene grounds, these may be less serious than the problems in handling waste effluents.

There are several considerations to keep in mind in evaluating problems and procedures in the utilization of cannery and freezer wastes:

1. Determine where the greatest pollution load problems occur in the handling of fruit and vegetable wastes. This involves determining

the volume and composition of the wastes and measuring their pollution strengths and magnitudes. This in turn would permit an evaluation of:

A. Potentials of possible treatments for the waste.

B. Potentials for use of the waste in light of current market practices, whether as feed or industrial derivatives.

C. Potentials for isolation, reduction or retention of the waste at the point of harvest.

D. Evaluation of possible methods for disposal of waste to the soil.

E. Determination of methods for reduction of discrete wastes within the process lines and reduction of leachates in all transport phenomena.

2. Investigate economic feasibilities in handling wastes consolidated from several plants where potentials for agricultural or industrial derivatives exist.

3. Investigate possible markets for new industrial products in light of changing needs: fertilizers, mulches and soil conditioners, chemical and nutritional derivatives, feed-stuffs and feed derivatives.

4. Consider establishing centers for research in solid waste utilization where industry may collectively support investigations and potentials in waste utilization.

Liquid Waste Treatment

There is a lack of information on the relative efficacy of simple screening and separation systems for the removal of colloidal and dispersed matter from effluents. There is potential application of such procedures at various stages in the processing of fruits and vegetables to remove the suspended and finer materials from the effluent streams. This will help reduce the pollution load in the plant effluent, and permit separation of water for treatment and reuse. There are only limited published data on the use of screens, vacuum systems, centrifugal systems and sedimentation systems for the treatment of selected effluent streams.

There is considerable engineering information on the disposal of effluent wastes upon soil. Soil type, pollution load, application rate, soil cover, and other conditions vary widely. The results have depended upon the experience of the participants in the projects. There is a dearth of information on the potential effects of the applications on the character of the soil from chemical interactions. It is evident that in many operations the effluent loads are being applied at maximum levels, resulting in some degree of run-off and development of undesirable odors. A compendium of engineering information for land disposal systems is needed.

The disposal of effluents in lagoon systems is widely practiced. The lagoons serve not only for biological degradation of effluent, but for storage as well. Commonly, lagoon operations depend on the natural flora, the nutrients available supplemented by nitrogen and aeration. There is a great need for information on establishing the optimum conditions for the biological degradation of the various types of effluents to achieve maximum effect in the shortest time. The information should include flora, temperature, concentration, pH, nutrient supplement and oxygen tension necessary to achieve maximum degradation. This information is needed to achieve efficiency in lagoon utilization and to minimize the hazards, which may occur when the lagoons are operated improperly. Lagoons are extensively used and are important tools in the treatment of wastes; the procedure is replete with problems in the light of increasing social and legal pressures.

The processing of effluents by systems which employ yeasts and fungi imperfecti and by trickling filters should be further examined to determine potentials in sequential treatment. This information is needed for the different types of wastes derived in processing fruits and vegetables to assist engineers in designing treatment systems.

Waste Pollution Evaluation

The concentration of pollution loads in most fruit and vegetable process wastes are measured by other than simple tests, such as Chemical Oxygen Demand (COD), or Biochemical Oxygen Demand (BOD). These are not simple in the sense that for reliability in the values obtained trained personnel must supervise their application.

The COD test is the more quickly performed (several hours; and the BOD_5 test requires five days, each after procedures have been standardized. These tests are used as the basis of acceptability of effluents disposed into natural waterways and in part to determine sewer charges.

A number of laboratory tests and instruments have been devised for quantifying the properties of waters and wastes. These range from sophisticated instruments for analysis for various components in water or wastes, to gross or proximate measurement of floc or precipitate. Many procedures have been applied in technical studies to characterize wastes and their degradation. Instrument manufacturers offer simplified forms of some tests to permit routine evaluation of some qualities of waters and wastes.

For routine surveillance by fruit and vegetable processors of the pollution loads in various steps of processing, there is a great need for at least two sets of evaluation procedures. The first is the need for data on the characterization of pollution load equivalent wastes of specific product processes as measured or interpreted by regular employees. Among these may be cited values obtained through use of laboratory instruments, such as turbidimeters, refractometers, centrifuges, conductivity meters, oxygen concentration meters, pH meters,etc.

The establishing of values from such instrument readings is highly desirable and presumably would be effective for supervision of pollution control. The second is the need for simplified "quick and dirty" procedures for measuring with reasonable reliability directly or indirectly COD equivalents of waste effluent streams in various stages of processing of various commodities. These should permit managers to monitor waste streams and treatments better than at present and should lead to better control of pollution problems.

Waste Treatment Management and Economics

The costs of liquid waste treatment and disposal are not available in a form which can be of guidance to individuals in management who must make final investment decisions. A Board of Directors must have information on available alternatives in meeting requirements for adequate treatment and disposal of wastes: In capital requirements, in reliability of results from the capital to be invested, in the cost effects on the product, and in competitive advantages in possible solutions to the problem.

Although much information is available on liquid waste treatment and disposal, it is nowhere consolidated in a manner which permits specific conclusions backed by authority, acceptable for making financial decisions for operations at a particular plant.

Management in some plants needs information which will enable it to meet minimum requirements in pollution control immediately; in others, action will be committed in a few years. There is, then, an immediate need for an informational compendium to aid management to act on its urgent problems. The form should allow expansion without major installational revisions.

The compendium should include, among others, the following:

1. A listing of the laws and ordinances affecting most processors, with a summary covering major restrictions.

2. A procedure for determining the cost of water supply, water handling and distribution, including its handling as waste and its recovery. It should include graphs for determining water costs.

3. Procedures for evaluating the effectiveness of various methods of screening of wastes to remove colloidal, suspended and smaller particulate matter; their relative merit for specific applications, and capital and operational costs.

4. Procedures for determining costs of municipal sewage service, including specific situation information with factor data for application to operations where the service is available.

5. Procedures for evaluating land disposal systems, including engineering factors, limitations, operational capabilities, capital and operational costs.

6. Procedures for determining costs of solid waste removal, utilization and disposal.

7. Recommendations for monitoring systems or procedures for control of pollution loads in wastes and effluents.

The compendium should include, first, a section which would be a concise summary of the problems facing a processing plant, relating these to economic and environmental problems and current external controls on how waste may be treated and discharged from the property. It should include evaluation of trends in enforcement by such external controls.

A second section should include a summary of current waste disposal possibilities expressed in costs in graphic form for application by management to mixes of suspended and soluble materials in the wastes. The graphs could relate the following:

1. Factors on the required work for different mixes of dissolved and suspended solids plus nutrients.

2. Relation between any given factor and investment and operation costs.

3. Relations between factors for various mixes and for different product wastes.

4. Relations between investment and operating costs against variable production levels for available methods of treatment, including municipal, land and biological degradation systems.

In order to implement the information useful to management in the treatment of wastes, there must be provided additional information about their character and further evaluation of systems for their treatment.

The relationship of the composition of the effluent to its biodegradability is not clearly established; for example, the rates of degradation of effluents bearing different types of organic solids, such as different types of vegetable starches, or of different types and concentrations of fruit acids.

The data should be implemented by information regarding measures to attain complete and rapid biodegradation of the wastes to the point of enabling economic treatment and recycling/reuse of the water. New engineering concepts may be feasible in the use of waste energy from stack gases or thermal processes applied to specific wastes or to biodegrading systems. Some information of this type has been developed. The efforts at treatment of wastes with unicellular microorganisms indicate the need for better understanding of the requirements to attain greater rates and more complete degradation.

REFERENCES

1. Bower, B. T., 1965. Unpublished data.

2. Boyle, W. E. and L. B. Polkowski, 1968. Observations of aerated lagoons for the treatment of vegetable cannery wastes. Sponsored by Wisconsin Canners and Freezers Assoc.

3. California State Water Resources Control Board, 1968. Cannery waste treatment, utilization and disposal. Publication No. 39.

4. National Canners Association, 1959. Unpublished survey of waste costs in canneries.

5. National Canners Association, 1970. Preliminary summaries of a survey of solid wastes from canning and freezing. For Bureau of Solid Waste Management, U.S. Dept of HEW.

6. Powers, T. J. III, B. R. Sacks and J. L. Holdaway, 1967. National Industrial Waste-water Assessment Manufacturing Year 1963. U. S. Dept. of Interior, FWPCA.

7. Secretary of Agriculture and Director, Office of Science and Technology, 1969. Control of Agriculture-related Pollution. Washington, D. C.

8. U. S. Dept. of Interior, FWPCA, 1967. The Cost of Clean Water, Vol. III, Industrial Waste Profiles, No. 6-Canned and Frozen Fruits and Vegetables.

9. U. S. Dept. Of Interior, FWPCA, 1969. The Cost of Clean Water and its Economic Impact, Volume I The Report.

10. U. S. Dept. of Interior, FWPCA, 1970. The economics of clean water - Volume I Detailed analysis.

PROGRESS REPORT: STUDY OF DRY CAUSTIC VS CONVENTIONAL CAUSTIC PEELING AND THE EFFECT ON WASTE DISPOSAL

by

Joseph W. Cyr*

INTRODUCTION

The dry caustic peeling system was originally developed by Graham, Huxsall, Hart, Weaver, and Morgan of Western Utilization Research and Development Division mainly as an attempt to reduce the waste generated in peeling potatoes and was later worked into an industrial process by Magnuson Engineers, Inc. of San Jose, California. Side benefits of lowered peel loss and reduced caustic usage have been observed by some processors and are being hunted for by others.

This study is being partially financed by the Environmental Protection Agency. The study was initially authorized in September 1969. Installation of the dry caustic peel lines, primary treatment systems, flow measurement instrumentation, sampling facilities and the necessary laboratory facilities have taken place during the intervening period.

The objectives of this study are as follows:

1. To determine total capital expenditures and operational costs of the dry caustic process and the conventional caustic process.

2. To compare the quantity and quality of the waste generated by the two systems.

3. To determine total water consumption, power requirements, and maintenance costs of the two systems.

4. To compare the silt removal systems and final clarifiers as to quality and quantity of influent and effluent.

5. To determine whether the dry caustic sludge would be accepted or rejected for subsequent study as animal feed material.

I would like to take this opportunity to thank Kenneth Dostal of E.P.A., Dr. Otis Sproul and Dr. John Vennes for their continual guidance in planning the study and also for their help in standard-

---

*Western Potato Service, Inc., Grand Forks, North Dakota

Preceding page blank

ization of the analytical procedures.

SUMMARY

1. Work to date shows about 4 times as much water usage in the wet as in dry caustic peeling. However, this will become nearly 8 times when water from the Magnuson washer is recirculated to the scrubber.

2. Pounds of dry solids to be dewatered/ton of potatoes to be peeled in the wet caustic peel system is 3-3/4 times that for dry caustic system.

3. Pounds of BOD/ton of potatoes to be peeled is nearly 4-1/2 times as much in the wet system as in the dry.

4. Capital costs show approximately $102,000 for the dry system vs $29,000 for the wet/line.

5. Operating costs including water are $0.46/ton for the dry systems in N.D., $0.49 for the wet in Me. If water costs were common to both plants at 10¢/1000 gallons the comparison would be $0.39 vs $0.49; at 80¢/1000 gallons, dry system would be $0.46 and the wet would become $0.89. The final report will include sludge handling and BOD removal costs where it is expected. The dry system will show lower costs than the wet.

DESCRIPTION OF PLANTS

Western Potato Service, Inc. processes roughly 120,000 tons of potatoes/year vs Potato Service, Inc's., 200,000. Both plants are highly automated and produce primarily frozen french fried potatoes. Both also produce several specialty items; namely, frozen hashbrowns, frozen cottage fries, frozen whole boils, frozen tators (at PSI only), and instant mashed potatoes. Water usage is roughly 1 mgd at WPSI and 3.5 mgd at PSI.

CAUSTIC PEEL AND PRIMARY TREATMENT SYSTEMS

Potatoes are flumed into the plants from plant storage and are stored in hoppers for even-flow to the peel lines. From the hoppers, the tubers are belt conveyed and weighed by Ramsey "Vey-R-Weight's" conveyor scales to the caustic reels and are then discharged onto retention belts. At this point, the two peel systems diverge. At WPSI, where the dry caustic peel system is in use, the tubers proceed over Magnuson shufflos, into the infra red units, thence to Magnuson scrubbers and finally to Magnuson washers. At PSI, where the conventional or wet caustic system is in use, the tubers after leaving the retention belt go to the roll brusher washers. These consist essentially of a series of cylindrical brushes with water spray nozzles directed downward onto the tubers.

With the dry caustic peel system, the bulk of the peel loss material (about 90 percent) is removed as a thick, heavy "peanut butter" like substance which is trucked off as is. The remainder is screened (20 mesh screens) and is then pumped to the clarifier. With the conventional or wet caustic system, the entire peel loss material goes down the flumes, passed through 4 mesh screens and then pumped to the clarifier. The primary clarifier is 60 feet in diameter at WPSI and allows for an approximate 5 hour retention time; at PSI, the clarifier is 100 feet in diameter allowing for 3-1/2 hours retention.

The Magnuson scrubbers are designed to use a minimum of water as are the washers. Good operation requires about 25 gpm through each set of units. The roll brusherwasher units on the other hand require approximately 500 gpm. Thus, the hydraulic, BOD, and suspended solids loads for primary treatment are markedly reduced when the dry caustic peel system is used.

TABLE 1

DRY SOLIDS AND WATER BALANCE

	Dry Solids pounds/ton		Water gallons/ton	
	WPSI	PSI	WPSI	PSI
INPUT:				
Fresh Water	4.8	1.46	1889.2	
Potatoes	400.0	387.3	191.2	
Fat	59.4	66.3		
Caustic	11.2	22.4	1.3	
SAPP, Sodium sulfite, and Bisulfite	4.8	3.6		
Dextrose	.3	.2		
Lime	3.8	0		
TOTAL INPUT:	483.5		2081.9	
OUTPUT:				
Peeler Solids	57.8	0	54.6	0
Screenings	16.1	18.7	9.6	11300
Clarifier				
Effluent	32.2		1508.4	
Sludge	30.5		49.8	
PRODUCT:				
Fries including waste + overage	232.9	242.5	67.5	71.2
Flakes including waste	30.5	38.5		
Flake mash waste	6.4	6.4	3.2	1.95
Compressor Operation			19.3	
Boiler Operation			110.8	
Fry Loss and Flake Dry Loss			25.7	20.5
Sanitary Sewerage			32.1	26.3
TOTAL OUTPUT:	406.4		1881.1	

Table 1: This is essentially a materials balance both for solids and for water. Potato solids were determined with a National Potato Chip Institute potato hydrometer. Note, too, that french fry waste and net weight average have been combined in the figure for french fry product; and flake waste is included in the figure for flake production. Since fresh water contained some solids, etc., the analytical results for fresh water were subtracted from those found in the waste, where consequential, to give true results.

TABLE II

CAUSTIC PEEL AND WASHER WASTES

	Pounds/Ton of Raw Material Processed
	WPSI
Water - gallons/ton	246.4
BOD	13.0
COD	23.1
Solids	
Total	23.6
Total Volatile	16.5
Suspended	17.0
Volatile Suspended	15.1
Settleable	.84
Nitrogen - Total Kjeldahl as N	.27
Phosphorus Total P	.11
pH	11.4
Alkalinity	3.22

Table II, The levels of waste generation at WPSI on a pounds/ton basis except in the case of water which is expressed in gallons/ton.

TABLE III

CLARIFIER EFFICIENCY

WPSI

	Clarifier Influent Pound/Ton	Clarifier Effluent Pound/Ton	Reduction %
Water - Gallons/Ton	1665.9	1648.2	1.06
BOD	40.0	24.1	39.8
COD	62.7	33.6	46.4
Solids			
Total	67.6	41.4	38.7
Total Volatile	57.8	21.3	63.1
Suspended	63.9	7.55	88.2
Volatile Suspended	47.6	5.43	88.6
Settleable	.51	.04	91.5
Nitrogen - Total Kjeldahl as N	1.34	1.06	21.0
Phosphorus, Total P	2.25	1.83	18.6
pH	10.8	6.6	
Alkalinity	13.88	8.58	38.2

Table III: This table shows the reduction both as a comparison between clarifier influent and effluent and as percentage reduction based on per ton of raw material input.

TABLE IV

CAPITAL AND OPERATING COSTS

	Caustic Dry	Peeling Wet
Capital Costs		
Equipment	$73,000	$21,500
Installation	18,250	5,400
Engineering	7,300	2,150
Operating Costs		
Maintenance	45,000	12,000
Operation		
Caustic	.128/ton	.256/ton
Gas	.062/ton	0
Power	.048/ton	.077/ton
Labor	.087/ton	.105/ton
Water	*.136/ton	**.056/ton

*Water at 80¢/1000 gallons
**Water at 10¢/1000 gallons

Table IV: This is a cost data sheet showing the comparison costs between the dry and wet systems. Note the differential in water costs.

TABLE V

SIGNIFICANT DIFFERENCES

	Peeling System	
	Dry Caustic	Wet Caustic
Water Use - Gallons/Ton	170	2800 (80% recirculated)
Clarifier Solids to be Dewatered pounds/ton	34	126
Clarifier BOD to Secondary Treatment pounds/ton	24.1	112

Table V: This is a summation of the significant differences between the two systems.

DRY CAUSTIC PEELING OF TREE FRUIT TO REDUCE LIQUID WASTE VOLUME AND STRENGTH

by

Jack W. Ralls*, Walter A. Mercer*, Robert P. Graham**,
Mark R. Hart** and Harry J. Maagdenberg*

INTRODUCTION

The preparation of tree fruits for preservation by freezing, dehydration or canning employs a complex technology and sophisticated equipment. The equipment and technology used in peeling tree fruit was developed over the years with high rates of production, adequate sanitation and optimum product quality as the principal design criteria. Until quite recently, only minor attention was paid to the effects of the peeling technology on the quantities and strengths of liquid wastes generated in the process as by-products.

Past and current research (and other water pollution abatement efforts) have, for the most part, emphasized "end of the pipe" handling and treatment of food processing wastewaters. Much time and large sums of money have been spent in testing and adapting methods of treatment and disposal for these liquid wastes. Rarely have any of the treatment systems used proven completely satisfactory. Variations in the nature and volume of food processing liquid wastes and inconsistent ability of different treatment systems to handle these variants have caused many problems. In-plant surveys made by research teams from the National Canners Association have shown that high percentages of the total dissolved organic solids in the composite wastewater originate in unit operations such as peeling and blanching of raw commodities.

The peeling of apples, apricots, and peaches produces 0.47, 0.16, and 0.42 lbs of B.O.D. per case of finished product, respectively (Anon., 1970). For peaches, the peeling operation, including the rinsing after peel removal, comprises 40.5 percent of the total lb of B.O.D. discharged in the composite liquid waste from a cannery (Spicher, et al. 1967).

Often individual waste streams representing no more than five percent of the total wastewater volume may contain 50 to 70 percent of the total discharge of dissolved solids. Generally, the concentrated waste streams are diluted by converging streams of comparatively clean waters.

---

*Western Research Laboratory, National Canners Association, Berkeley, California.

**Western Utilization Research and Development Division, Agricultural Research Service, United States Department of Agriculture, Albany, California.

It has become increasingly apparent in recent years that it is more efficient to abate water pollution by changing processing technology rather than by expanding treatment facilities. There are many potential ways in which foods can be prepared for preservation which will drastically reduce the volume and strength of wastewaters generated. An engineering development of the past three years in radical modification of conventional food processing technology to reduce liquid waste volume and strength is the "dry caustic" peeling of potatoes. This process resulted from work at the Engineering and Development Division, Agricultural Research Service, United States Department of Agriculture, Albany, California (Graham, et al., 1968, 1970) and Magnuson Engineering, Inc., San Jose, California (Smith, 1969, 1970).

The new process, now known as the USDA-Magnuson Infrared Anti-Pollution Peeling Process, uses infrared energy at 1650°F to condition the surfaces of potatoes treated with strong sodium hydroxide solutions. The peel can then be removed mechanically by soft rubber scrubbing rolls rather than by water as is done in conventional caustic peeling. A final spray rinse using low volumes of water removes a residual peel fragments and excess sodium hydroxide. The effluent from the peeled potato rinsing may be combined with the solid material generated to produce a thick, yet pumpable, sludge.

Direct comparison of the new process with conventional peeling has demonstrated that the strength of the waste discharged has been reduced by 40 percent (Graham, et al., 1970). This result means that the capacity of secondary treatment plants required to condition the effluent to a satisfactory B.O.D. and suspended solids level (Dostal, 1969) could be greatly reduced with substantial overall savings in equipment and operating costs. In situations where the potato processing effluent is treated in a municipal system in combination with domestic sewage, the resulting lower loadings allow for population growth in the area served by the plant without requiring costly expansion.

The tonnage of potatoes processed each year is substantial and reduction of water pollution caused by this commodity received first attention by scientists and engineers. However, there are other food commodities which are chemically peeled and extension of the "dry caustic" peeling process to these would provide the potential for significant water pollution abatement. For example, the weight of tree fruit peeled by chemical methods was about 1,000,000 tons in 1968. Each ton of apricots, peaches (Mercer, et al., 1965) or pears processed produced, on the average, about 12 pounds of B.O.D. and 9 pounds of suspended solids in the rinse water used in conventional chemical peeling. If only a 40 percent reduction in strength of wastes from plants peeling these fruits were achieved by "dry caustic" peeling some 5,000,000 pounds of B.O.D. and 3,700,000 pounds of suspended solids would be removed from the effluent waste streams each year.

This report describes results from a collaborative project between the USDA and NCA to extend the water pollutional abatement potential of "dry caustic" peeling of potatoes to apricot, peach and pear peeling. The utility of the new peeling process for these three tree fruits was shown to be promising in exploratory studies (Graham, 1970, Hart, et al., 1970). The potential for substantial reduction of water polluting liquid waste volume and strength by the new method of peeling tree fruit was recognized by the EPA (formerly FWPCA of the Department of the Interior) and funds were made available to support an investigation.

CONSTRUCTION OF PEEL REMOVAL UNIT

Construction of the peel removal unit, as shown in a general concepts drawing in Figure 1, was accomplished by the USDA in Albany, California. An employee of the NCA was assigned as a collaborator in assisting USDA employees in the construction.

The shaft for each spindle of rubber disks, spacers, and stiffeners were cut from 1/2 in. stainless steel rod. One-half, 1/4, and 1/8 in. spacers were cut from clear plastic sheets; all spacers were 1-5/8 in. in diameter.

Nineteen slots for one five ft section and 20 slots for the second section were milled from 4 in. by 1/4 in. x 5 ft aluminum sheets to accommodate the spindle shafts. A similar number of matched undersize slots were milled from 1-3/4 in. by 1/2 in. by 5 ft nylon sheet. One-eighth in. by 2 in. steel angles were cut, drilled and tapped to form the support structure; this was assembled by using 3/8 in. by 5/12 in. round head screws. The peel catching tray was fabricated from sheet metal (See Figure 2).

The idler gear support bar was constructed from 1 in. by 1/2 in. by 5 ft aluminum bar stock. Holes were drilled and tapped in the bar as shown in Figure 3. Spindles were held in position by a clamped 1/4 in. by 3/4 in. by 5 ft aluminum bar. Figure 4 shows the standard gear arrangement using #18 sprocket gears with # 8 idler gears. A differential gear arrangement used alternate #16 and #20 sprocket gears in place of the #18 gears of the standard arrangement.

The disk cover was fabricated from #20 gauge stainless steel sheet as shown in Figure 5. A 1/8 in. clear plastic cover was loosely fitted on each metal cover section; these were fitted with two wooden knobs to facilitate removal.

Two spindle carriers similar to those fabricated from aluminum were constructed from 3/4 in. exterior plywood.

The starters and variable drive motors (3/4 H.P.) were positioned as shown in Figure 1. The starters were first attached to brackets and then positioned to the welded rectangular frame support. The motor bases were connected to 3/4 in. exterior plywood and then clamped to the steel frame support. V-belts and pulleys were connected and galvanized steel belt guards constructed and attached to the units. In the initial trial runs with peaches, an equipment modification was needed to prevent the peach halves from spinning in place along the sides of the disk cover. One-half in., half round wood stock was cemented to the cover (as indicated by the insert in Figure 5) to overcome this spinning action.

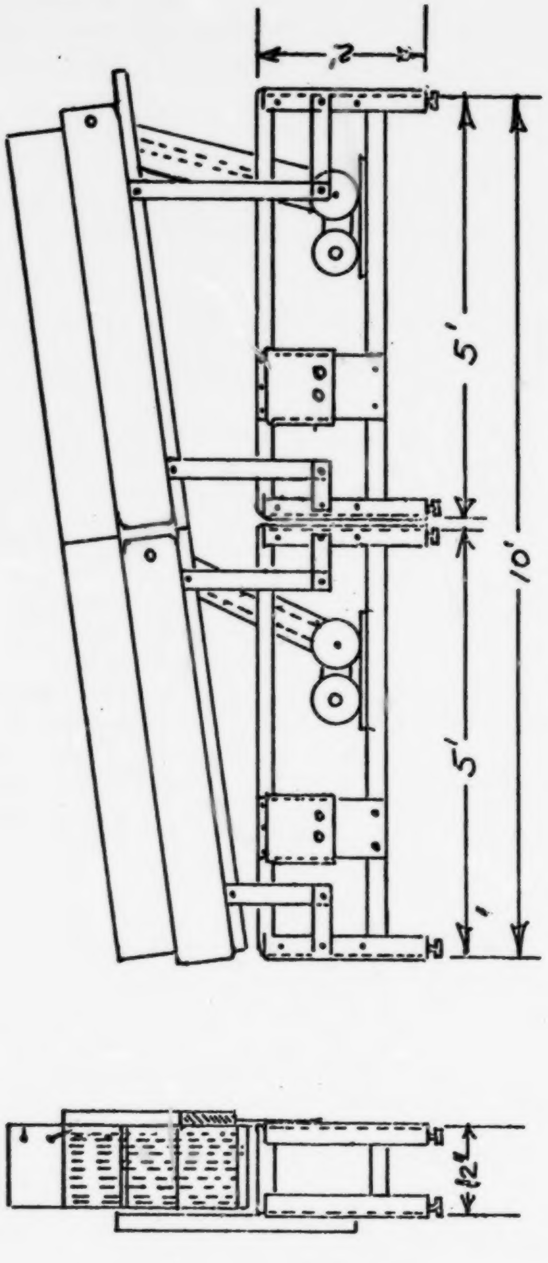


Figure 1

Peel Removal Unit, General Concept

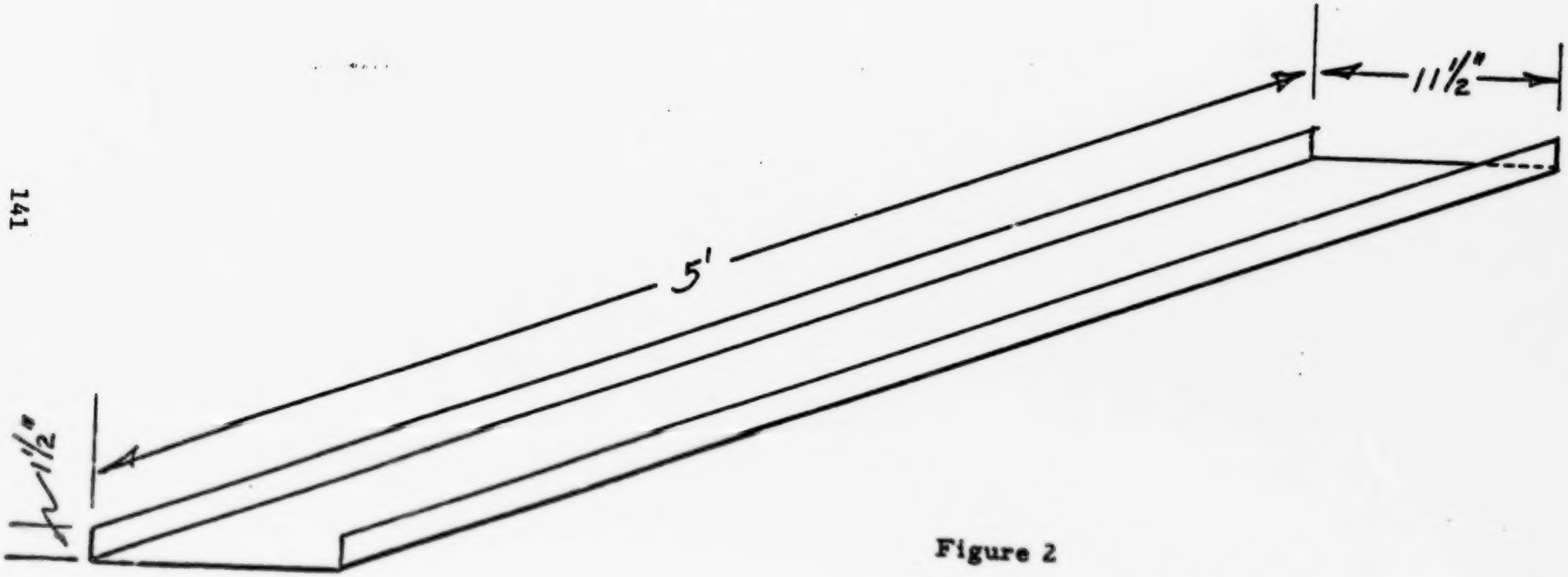


Figure 2

Peeler Tray

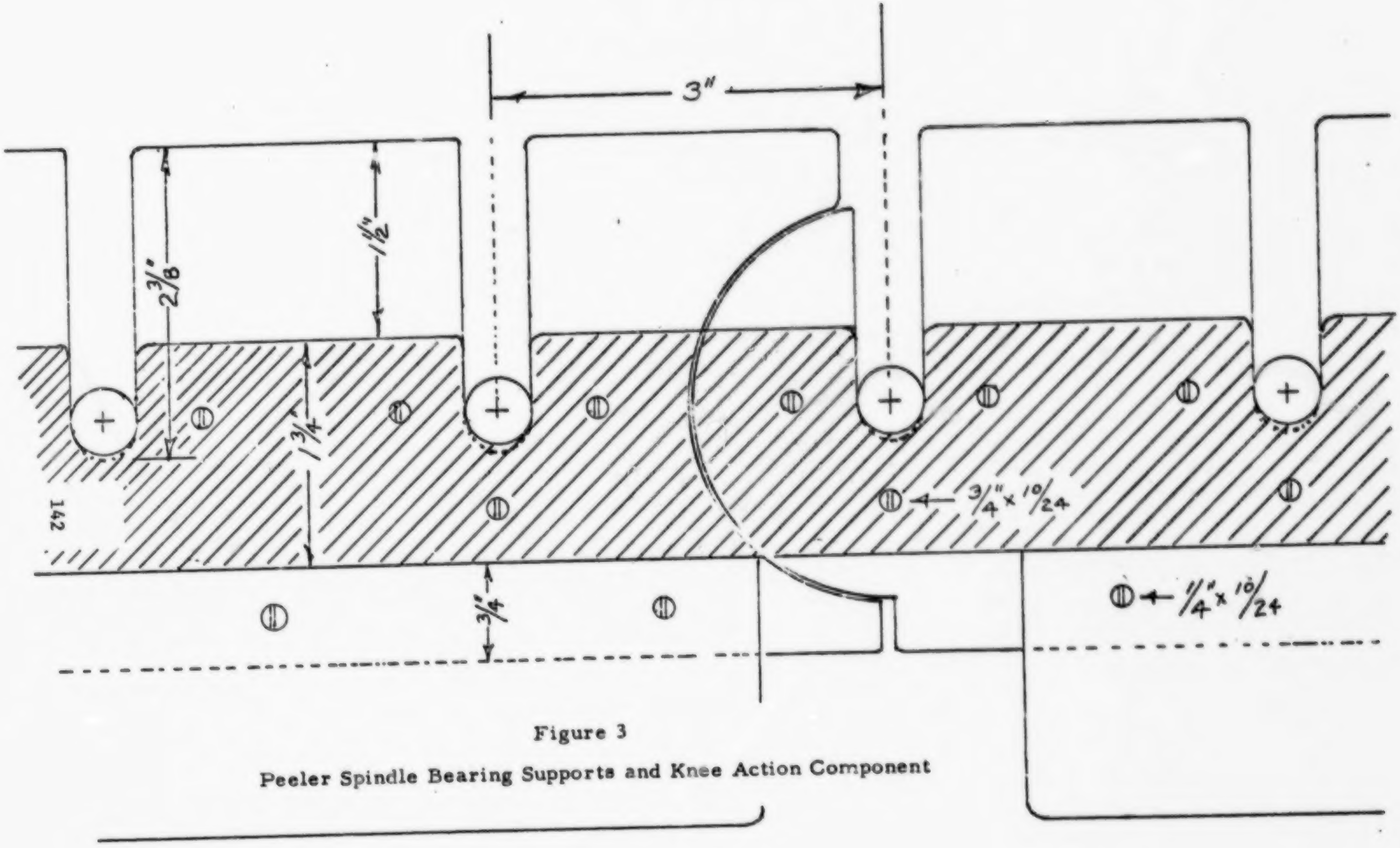


Figure 3

Peeler Spindle Bearing Supports and Knee Action Component

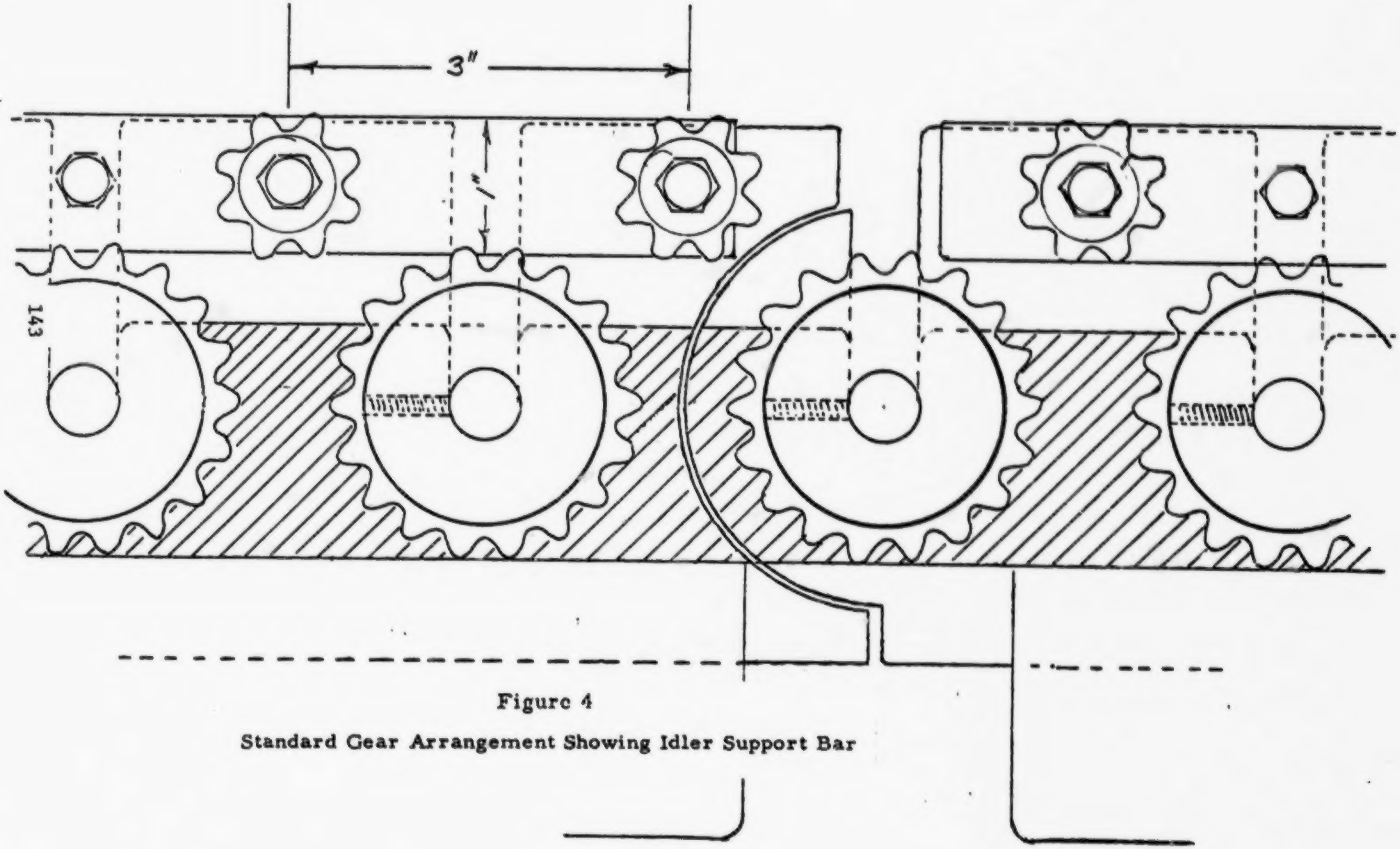


Figure 4

Standard Gear Arrangement Showing Idler Support Bar

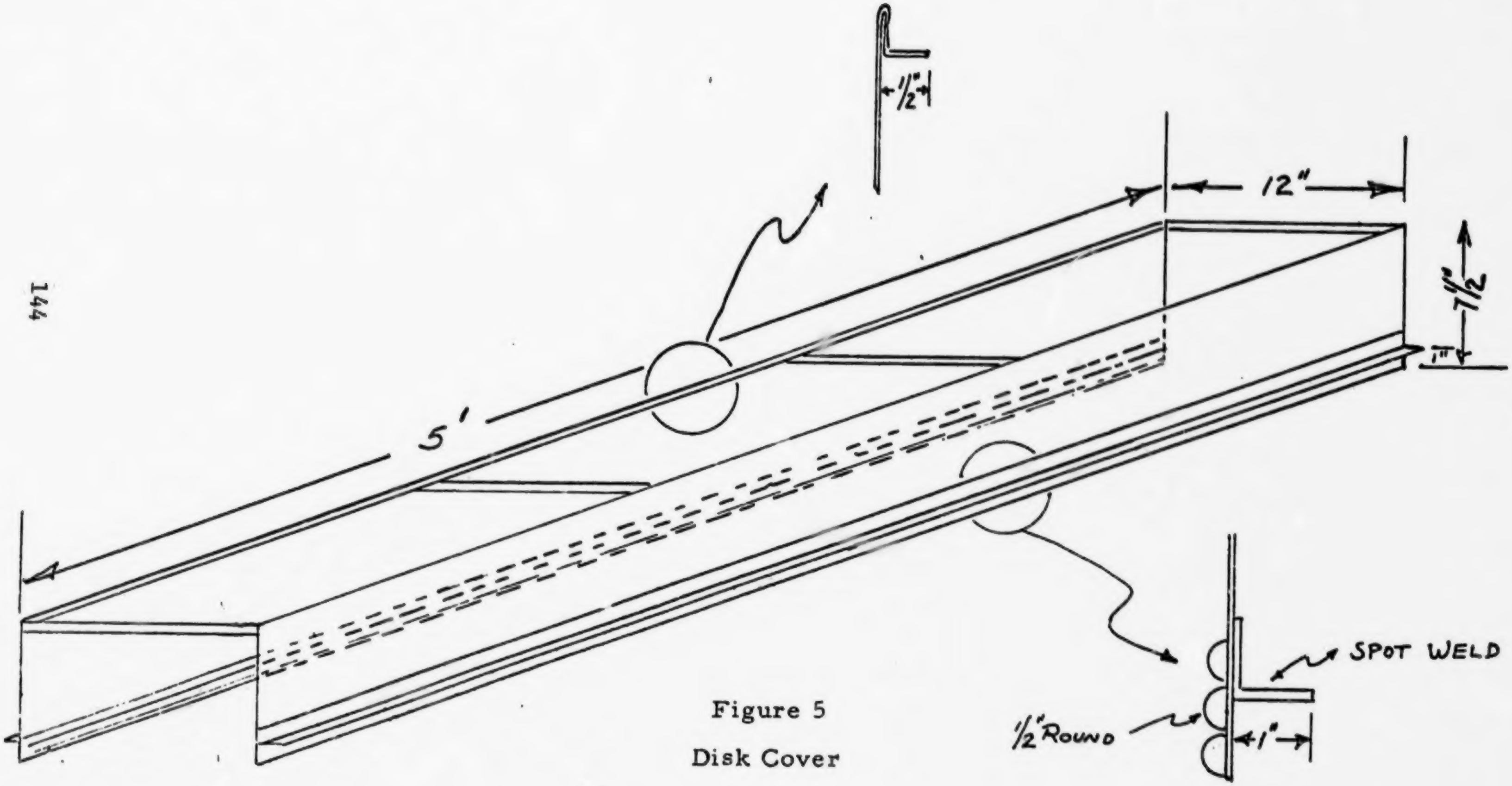


Figure 5

Disk Cover

Another modification, the use of wiper bars in the second tray section, (Figure 6) was introduced to remove a large amount of tacky material from pears before they came in contact with the fresh water.

The custom fabricated neoprene rubber disks (See Figure 7) were not delivered until after the apricot peeling had started. The disks used for the apricot peeling experiments were fabricated and assembled by hand. Four and 1/4 in. diameter by 1/32 in. thick disks were cut from a roll of Shore A, durometer 50 (Anon., 1958) food grade rubber sheet. One-half in. diameter holes were punched out of both the rubber disks and 2-3/4 in. diameter Mason jar lids used as stiffeners. The spindles were assembled on the stainless shafts using the plastic spacers.

Six different sequences of spindles were used for peeling experiments on apricots, peaches and pears. Three of the sequences used 39 identical spindles and three of the sequences used a combination of several different spindle configurations. The ten different combinations of rubber disks, spacers and stiffeners used for spindle configurations have been assigned numbers and are shown diagramatically in Figures 8 through 10.

The sequences of individual spindle configuration in the 39 slots provided for the spindle shafts are designated by the letters A through F. The spindle sequence A consisted of 39 identical spindle configurations disignated by number 1. The spindle sequence F consisted of 39 identical spindle configurations designated as number 2. The spindle configuration D consisted of 39 identical spindle configurations designated by number 4. The spindle sequences using a combination of different spindle configurations to fill the 39 shaft slots were designated B, C, and E and are identified in Table 1. The shaft position numbers start with 1 at the feed end of the peel removal section.

OPERATION AND EVALUATION OF FRUIT PEELER

Peeling of Peach Halves

The major effort in this study of peeling certain tree fruit was concentrated on evaluation of peel removal from peach halves. The bulk of peaches harvested for processing are peeled before preservation.

The work on peach peeling was accomplished in a commercial cannery in Richmond, California. This was done for several reasons. The cannery location provided adequate supplies of peaches of commercial grade, pitted with conventional equipment, and potentially returnable to production. Experienced plant personnel were available to provide estimates of the quality of peeled peach halves. Also, commercial scale equipment was available for use in applying sodium hydroxide solution.

The equipment used is shown schematically in Figure 11. The experimental peeling of peach halves was conducted in the following manner. Peach halves from the Filper pitting machines were placed in 5 gal. stainless steel pans and the peach weight was measured. The peach halves were dumped into an elevator which delivered them to a cup down shaker. The oriented peaches were conveyed through a commercial sodium hydroxide

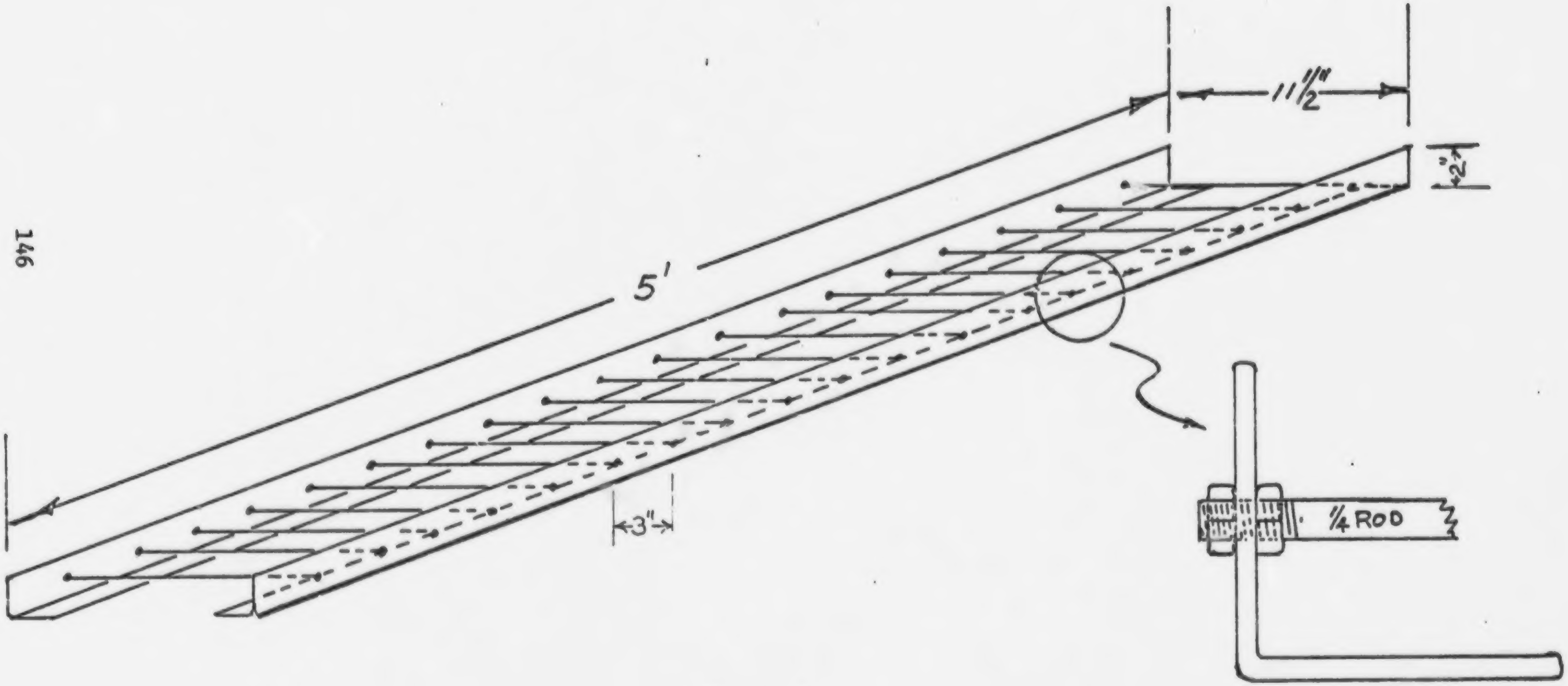


Figure 6

Disk Scraper Inserted In Spindle Housing

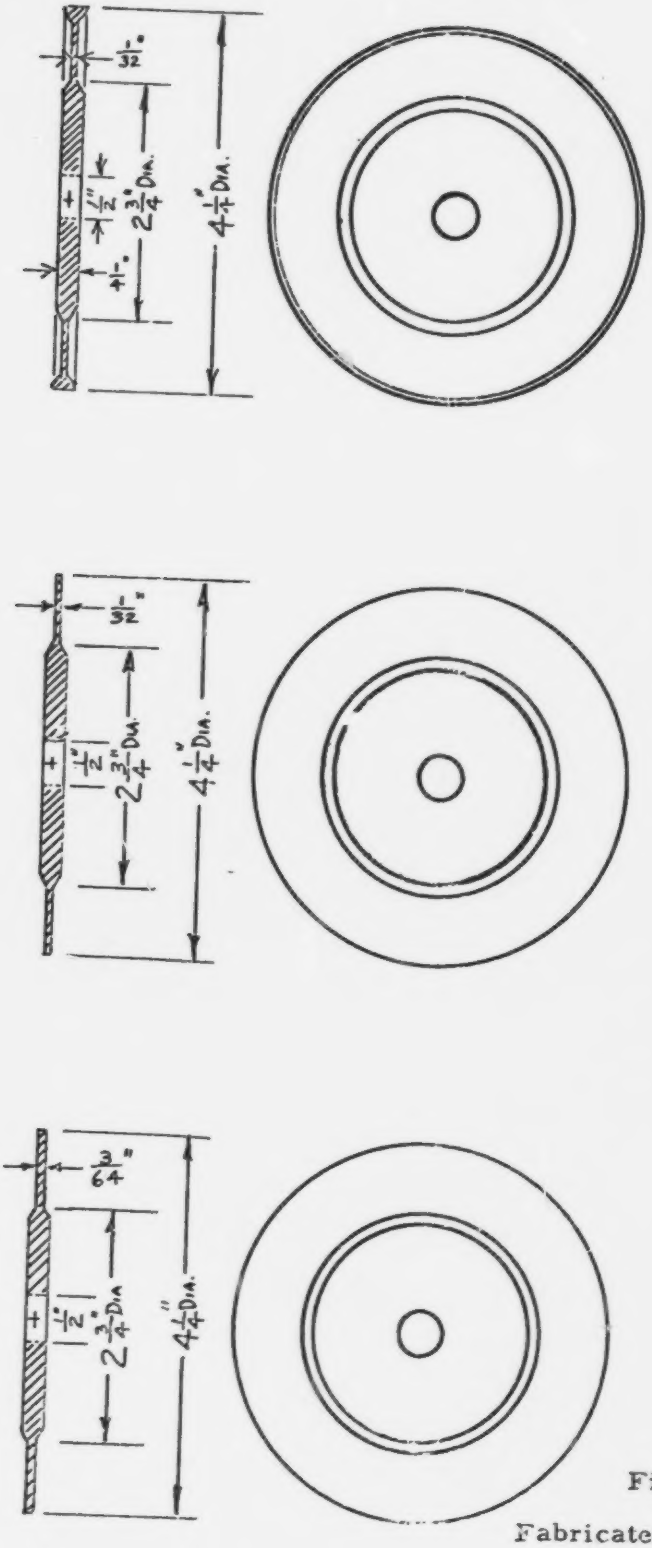


Figure 7

Fabricated Rubber Disks

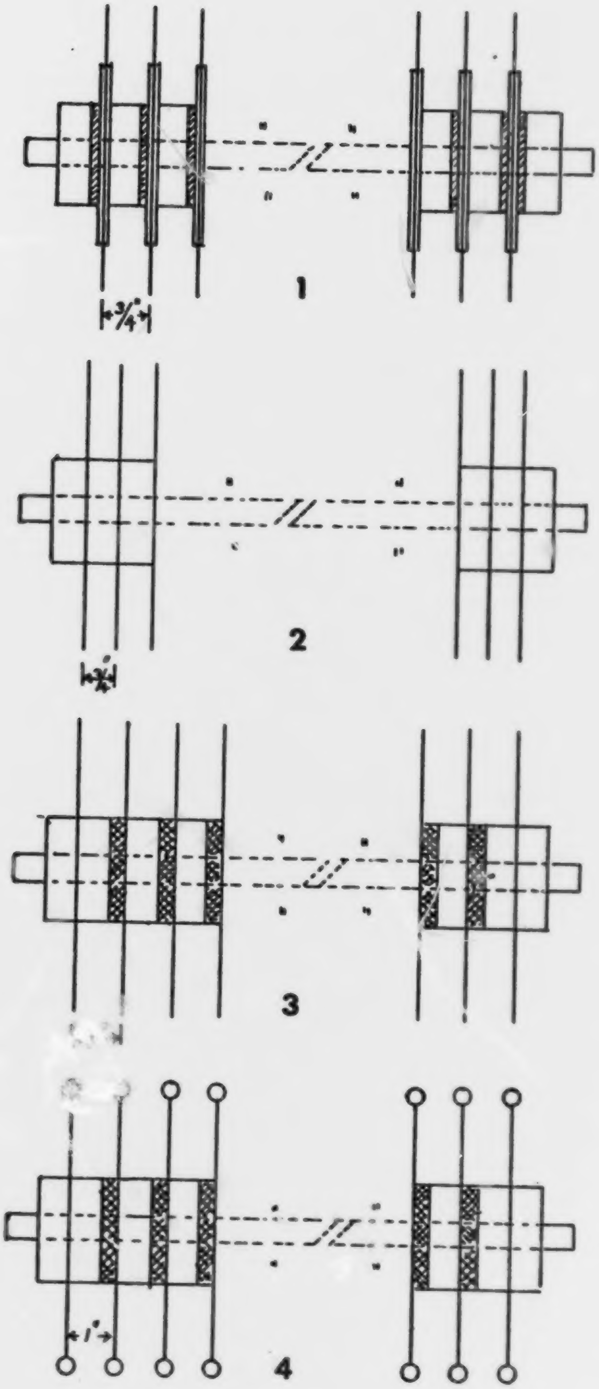


Figure 8

Peeling Disk Configurations

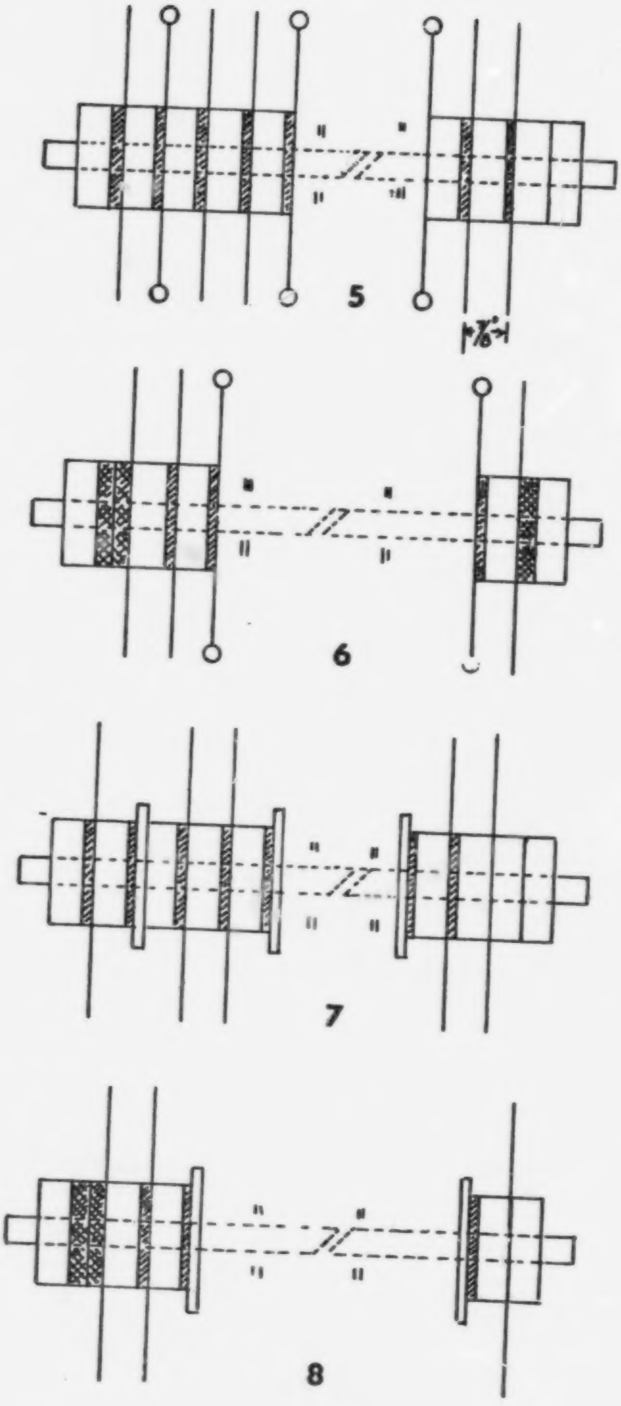


Figure 9

Peeling Disk Configurations

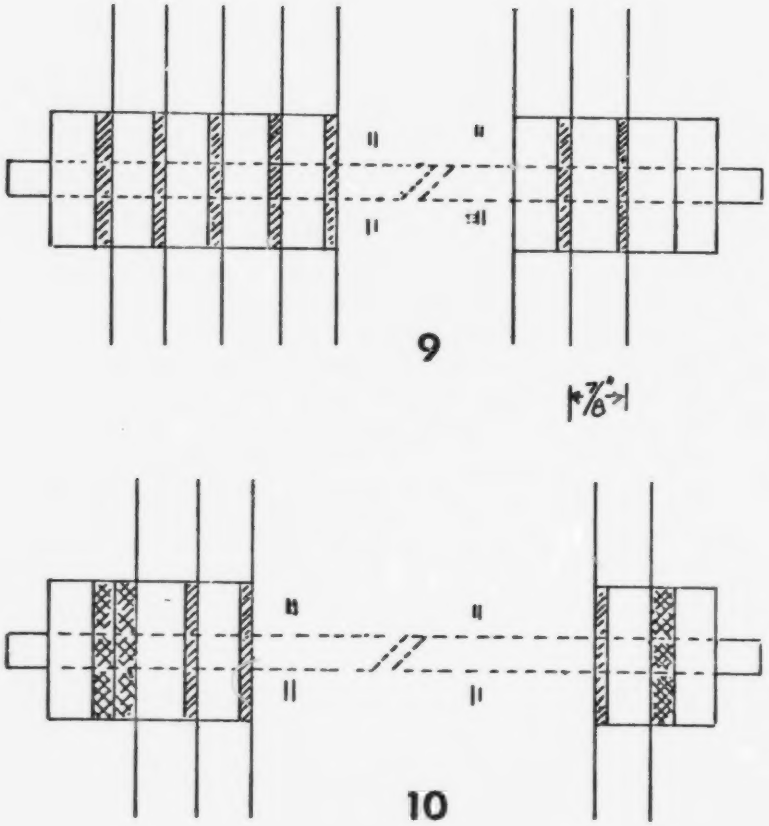


Figure 10

Peeling Disk Configurations

TABLE I

SEQUENCE OF SPINDLE CONFIGURATIONS USED FOR THE SHAFT POSITIONS OF PEEL REMOVAL UNIT

Shaft Position Number	SEQUENCE		
	B Spindle Configuration*	C Spindle Configuration*	E Spindle Configuration*
1	6	10	3
2	7	7	3
3	8	8	3
4	5	9	4
5	6	10	3
6	5	9	3
7	8	8	3
8	7	7	4
9	6	10	3
10	5	9	3
11	6	10	3
12	7	7	4
13	8	8	3
14	5	9	3
15	6	10	3
16	5	9	4
17	8	8	3
18	7	7	3
19	6	10	3
20	5	9	4
21	6	10	3
22	7	7	3
23	8	8	3
24	5	9	4
25	6	10	3
26	5	9	3
27	8	8	3
28	7	7	4
29	6	10	3
30	5	9	3
31	6	10	3
32	7	7	4
33	8	8	3
34	6	10	3
35	5	9	3
36	6	10	4
37	8	8	3
38	7	7	3
39	6	10	3

*See Figure 8 through 10.

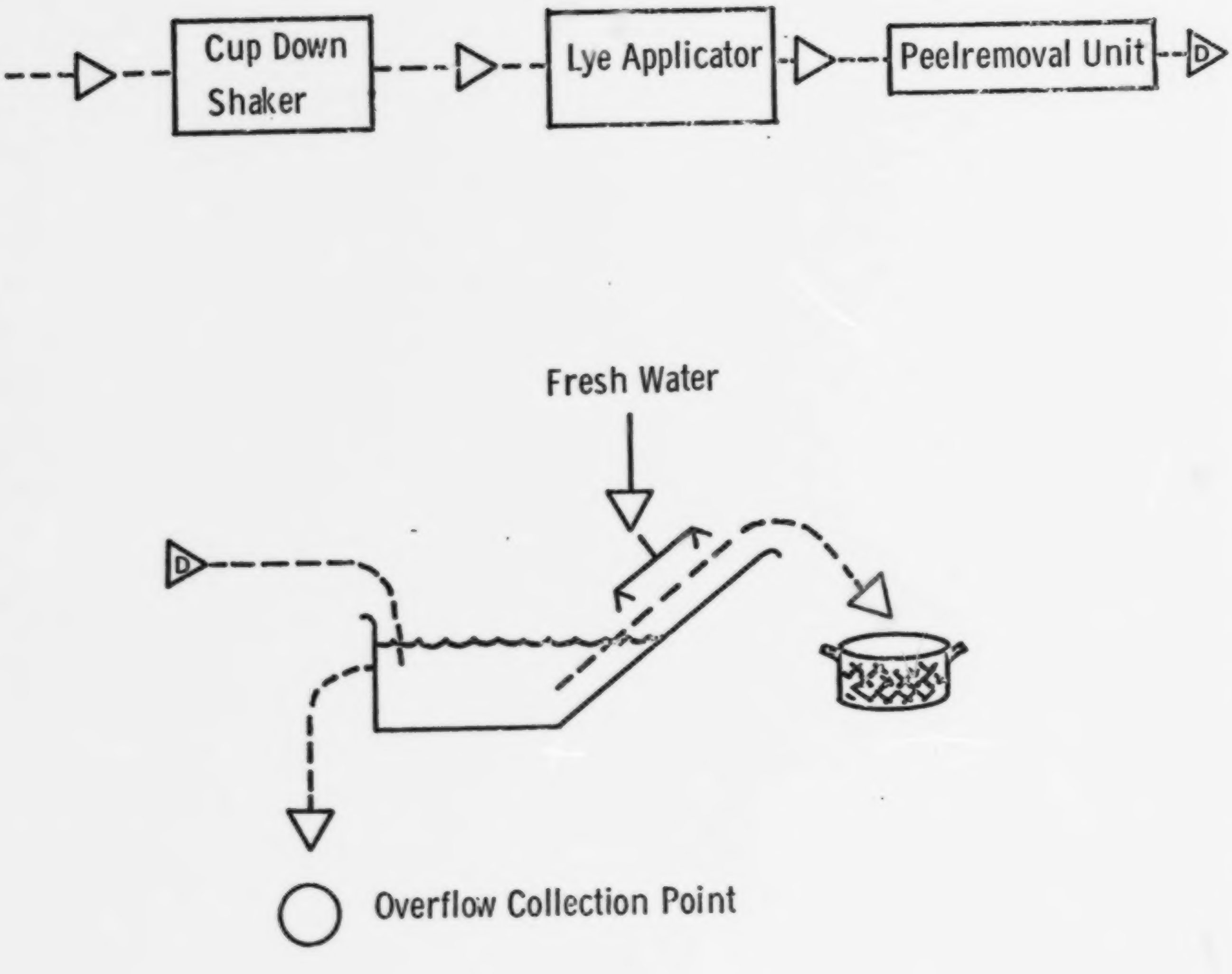


Figure 11

Schematic Drawing of Experimental Peach Peeling Equipment solution applicator. The coated peach halves were drained of excess sodium hydroxide solution and delivered by a sheet metal trough to the peel removal unit. The peach halves moved through the unit and dropped down a chute at the exit end into a surge tank filled with water. The submerged peaches were removed from the surge tank by an elevator with a 45 degree pitch into tared receivers. One to three spray heads provided a rinsing of the peaches in the elevator before delivery into the tared containers. The fresh water introduced at the spray heads drained into the surge tank as make-up water. The surge tank was fitted with an overflow pipe which emptied into containers for volume measurement and wastewater sample collection. The peeled peaches were examined for peeling quality by visual inspection, weighed, and returned to the Filper pitter discharge flume to be used in commercial production.

A large number of preliminary experiments of short duration were used to determine good operating conditions. The major variables studied during the preliminary runs were: sodium hydroxide concentration, sodium hydroxide bath temperature, residence time of peach halves in sodium hydroxide applicator, drain time for coated peach halves, peeling disk type and spacing, feed rate, peel removal section slope and disk turning speed.

Table II summarizes the results of longer duration peeling experiments with peach halves using the best operating conditions developed during preliminary, short duration experiments. Peeling losses were determined in 3 min. runs using conditions identical to those used in the runs of approximately one hour duration.

TABLE II

RESULTS OF PEACH HALF PEELING USING ROTATING RUBBER DISK PEEL REMOVAL UNIT

Run No.	Feed Rate, lb/hr	NaOH Strength Percent	Peel Removal Unit Slope, in./10 ft	Peeled Fruit Quality	Peeling Loss, Percent
8-21-2*	4119	1.5	15	Good	N.M.***
8-21-1A	4286	1.4	15	Good	5.1
8-21-2**	4647	1.5	9	Fair	N.M.
8-21-2A	4996	1.4	9	Fair	4.7

---

*Duration of run was 61 minutes

**Duration of run was 56.3 minutes

***N.M. = Not Measured

Table III tabulates the water volume used in rinsing peeled peach halves and analytical values measured on wastewater samples.

The wastewater overflow from the surge tank was collected in a 55 gal. drum. A one gal. sample was removed from the drum at 15 min. intervals

TABLE III

RINSE WATER VOLUME AND WASTEWATER CHARACTERISTICS FOR PEACH HALF PEELING

Run No.	Rinse Water Rate gal. /hr	Rinse Water Rate gal. /ton	Wastewater Sample*	Wastewater Quality COD, ppm	Wastewater Quality SS, ppm	Wastewater Quality pH
8-21-1	75	36	15 G	30,000	7,200	9.4
			30 G	60,000	12,400	9.7
			45 G	63,300	7,300	9.8
			60 G	97,400	12,480	9.7
			61 C	75,700	10,850	9.7
8-21-2	77	33	15 G	30,000	7,200	9.4
			30 G	53,900	10,150	9.4
			45 G	69,100	12,600	9.6
			56 G	63,300	18,400	9.7
			56C	50,200	9,750	9.5

---

* Time in minutes, G = grab, C = composite.

TABLE IV

WATER VOLUME REQUIREMENTS AND WASTEWATER CHARACTERISTICS FOR COMMERCIAL CLING PEACH PEELER

Fresh Water Input, gal. /ton	Wastewater Sampling Point*	Wastewater Volume, gal. /ton	Measurements C.O.D., ppm	Measurements SS, ppm	pH
600	1	400	5,300	1,230	11.3
	2	200	19,600	2,430	10.2
540	1	360	5,600	1,060	11.6
	2	180	16,700	1,280	10.3
580	1	387	5,100	780	11.1
	2	193	6,600	1,950	10.1
525	1	350	5,900	1,150	11.1
	2	175	23,000	3,080	10.1
460	1	307	5,100	1,320	11.0
	2	153	30,000	5,640	10.7
515	1	347	5,100	1,540	11.2
	2	168	25,100	5,640	10.7
470	1	313	4,900	910	11.3
	2	157	31,700	5,240	10.7
Ave. 527	-	527	13,550	2,375	10.8

---

* See Figure 12

after mixing the contents of the drum. A composite sample was prepared by mixing 0.5 gal. portions of each of the 15 min. grab samples.

For comparative purposes, wastewater samples were collected from the commercial peach half peeling unit (See Figure 12) and analyzed. The results are tabulated in Table IV.

Peeling of Whole Pears

The peeling of whole Bartlett pears was conducted at two locations. A limited number of short duration peeling experiments with pears were run in the commercial cannery with the sodium hydroxide applicating equipment used for the peach half peeling. It was too difficult and potentially dangerous to project personnel to obtain sodium hydroxide treated pears from the commercial equipment in the cannery. The commercial peeler has a pressurized section following the sodium hydroxide application zone. The pears are conveyed through an air-lock from the pressure section to a lowerator which delivers the partially peeled pears to a flume. Removing pears from the lowerator was judged by the Project Director to be hazardous due to the restricted clearance between lowerator flights and sidewalls which could catch and break hands and arms. Beyond this consideration of safety, the treated pears at this point had lost considerable portions of their peel and were not the best material for peeling experiments.

Extensive experimental peeling of pears was conducted at the USDA Laboratory in Albany, California due to inadequate clearance space between belt and cover for the commercial peach sodium hydroxide applicator in Richmond. A screw drive sodium hydroxide applicator unit was used for these experiments. The results of three longer duration peeling experiments on pears are tabulated in Table V.

TABLE V

RESULTS OF WHOLE BARTLETT PEAR PEELING USING ROTATING RUBBER DISK PEEL REMOVAL UNIT

Run No.	Feed Rate, lb/hr	NaOH Strength Percent	Peeled Fruit Quality	Peeling Loss, Percent
10-2-1*	1,700	15.2	Good to Poor	11.3
10-16-4**	2,050	17.3	Good	20.4
10-28-1***	1,786	17.0	Good	15.8

*13.0 minute run
**12.3 minute run
***30.1 minute run

The rinsewater volume used in Run 10-28-1 of Table V was 89.4 gal. per ton and the wastewater had a C.O.D. of 10,500 ppm, a SS content of 2550 ppm and a pH of 10.6. The rinse water for the pear peeling consisted of

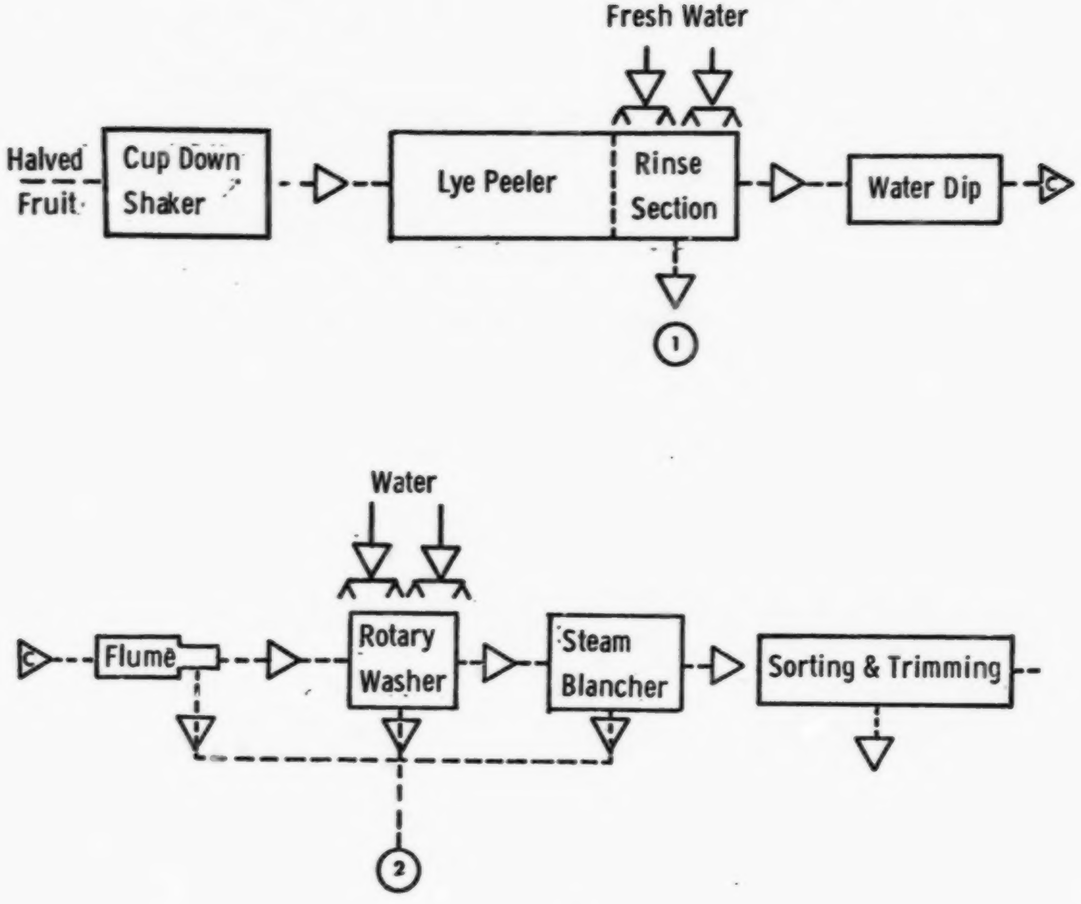


Figure 12

Schematic Drawing of Commercial Peach Peeling a tank containing 20 gal. of water. Analysis was made on a composite sample of water from the rinse tank.

For comparison purposes, wastewater from a commercial pear peeling unit (See Figure 13) was collected and analyzed; the pH was 10.5 and the C.O.D. was 5,040 ppm. The rinse water volume was estimated as about 200 gal./ton of fresh pears.

Three facets of pear peeling were examined during the project. The sizing and firmness of pears are important considerations in their peeling performance by the methods used at the present time. Measurements of size distribution of pears peeled successfully were made to provide industry specialists with information which they could correlate with their experience using conventional peeling equipment. The size distribution of a typical lot of pears is tabulated in Table VI.

Another important factor in pear peeling by conventional methods is the firmness of the pears. Firmness is measured by reading the force necessary to insert a rod into a pear (at a point where the skin has been removed with a knife) to a standard depth. The results of the penetration testing of a lot of 33 pears typical of those used in the experimental peeling are tabulated in Table VII. The results of the firmness testing indicated that the pears used were in the normal range for successful commercial peeling.

The peel material, which is wiped from the fruit drops or is spun down as a sludge to the bottom of the peel removal unit tray and drains (or can be scraped) counterflow to the peeled fruit. The peeling sludge can be handled as a solid waste material. As disposal of solid waste in land fill becomes more difficult in the future due to lack of appropriate sites, the peel sludge has potential as a component of animal feed. A limited amount of information on the composition of the peeling sludge was obtained during the project. The weight of the sludge is approximately represented by the peeling loss. No direct measure of peeling sludge weight was possible due to the deposition of part of this material on the walls of the equipment. It was impractical to determine the weight of the deposited peel sludge as well as to account for losses of material spun away from the unit from the peeling disks (by centrifugal force).

Values for the content of sodium hydroxide and sodium carbonate in the pear peeling sludge is tabulated in Table VIII.

Peeling of Whole Apricots

A number of short term peeling experiments were completed at the USDA Laboratory in Albany, California using Blenheim and Tilton apricots obtained from canneries in the San Francisco Bay area.

Due to the delay in delivery of vulcanized rubber peeling disks, time allocated to the construction of a spray rinsing section was diverted to assembling peeling disks by hand. The rinsing of peeled apricots was by simple submersion in fresh water contained in a tank. The wastewater generated was considered as not representative of wastewater from a spray rinsing unit. Therefore, no wastewater samples from apricot peeling experiments were collected.

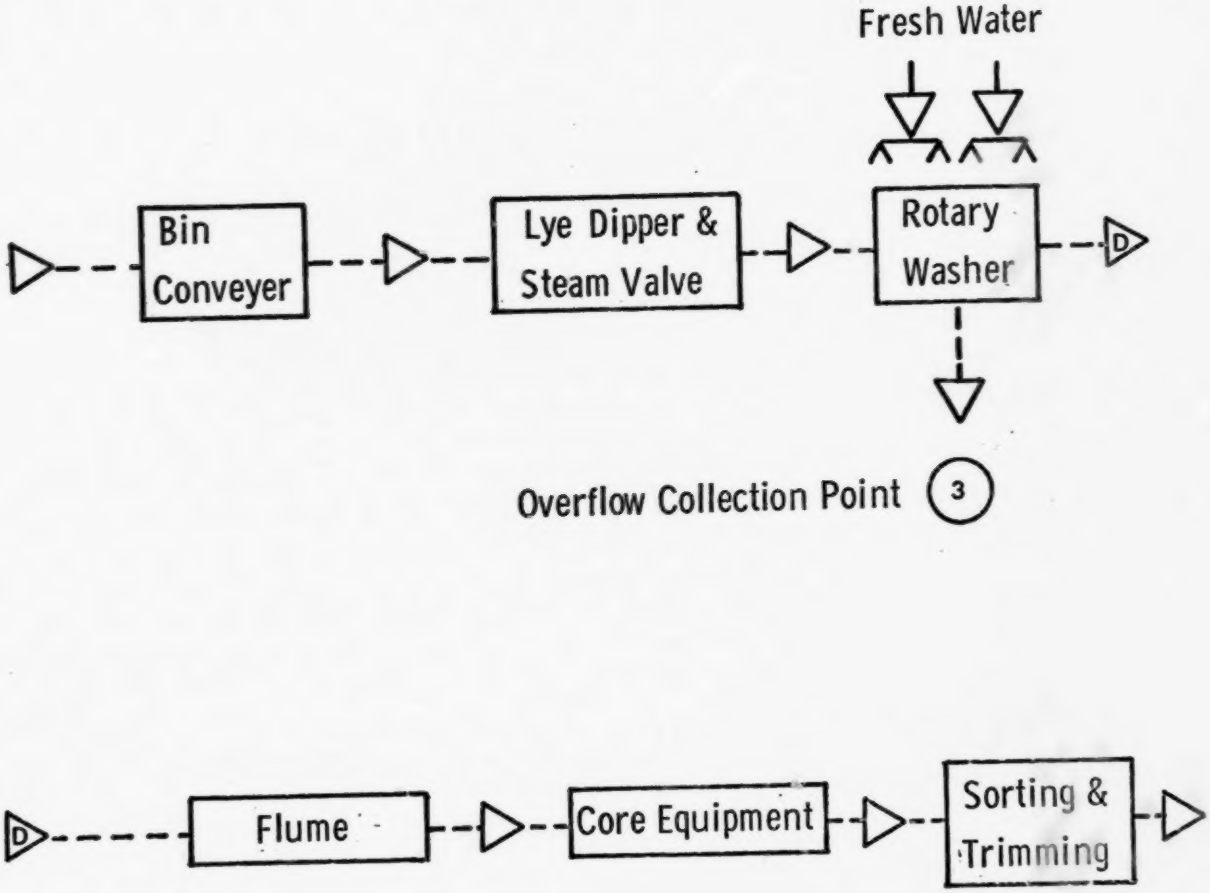


Figure 13

Schematic Drawing of Commercial Pear Peeling

TABLE VIII

SODIUM HYDROXIDE AND SODIUM CARBONATE CONTENT OF PEARS PEELING SLUDGE

Sampling Date	Solids, Percent	NaOH Wet Wt, Percent	Na_2CO_3 Wet Wt, Percent
9-29-1	27.3	3.8	2.6
9-29-2	27.0	2.1	2.4
9-30-1	23.6	2.0	1.8
9-30-2	20.8	0.6	1.4
10-1-1	21.6	1.7	1.6
10-1-2	18.4	0.3	0.9
10-5-1	22.4	1.7	1.3
10-6-1	22.2	1.1	1.4
10-13-1	28.5	3.8	2.5
10-13-2	24.0	1.8	2.3
10-14-4	24.9	2.9	1.8
10-14-5	20.2	1.2	1.2
10-28-1	23.5	2.2	2.3
Average	23.4	1.9	1.8

The results obtained during the peeling of Blenheim apricots are tabulated in Table IX. The results obtained during the peeling of Tilton apricots are tabulated in Table X.

TABLE IX

RESULTS OF SHORT DURATION PEELING EXPERIMENTS ON MIXED SIZE BLENHEIM APRICOTS

Run No.*	6-18-6	6-19-1	6-19-2	6-19-4	6-19-5
NaOH Conc., %	25-30	25-30	25-30	25-30	25-30
NaOH Temp. °F	210	150	140	160	150
Disk Rotating Speed, RPM	266	266	373	373	373
Peeler Slope, in./10 ft	-4	0	0	4	4
Feed, lb	60	30	30	30	30
Feed Time Sec.	240	90	35	90	90
Feed Rate, lb/hr	900	1200	3080	1200	1200
Peeled Weight, lb.	53.9	27.6	29.3	26.3	27.3
Washed Weight, lb	42.7	25.0	27.5	25.3	26.1
Total Peel Loss, %	28.8	16.7	8.3	15.6	13.0
Gears Used	S**	S	S	D	D***
Peeled Fruit Quality	N.R.	N.R.	N.R.	N.R.	N.R.
Rinse Water, gal.	5.0	5.0	5.0	5.0	5.0
Rinse Water, gal./ton	167	333	333	333	333
NaOH Dip Time, Sec.	33	70	70	70	70

---

*Spindle sequence was F in all runs.

**S - Standard

***D - Differential

N.R. - Not Recorded

DISCUSSION

The operation of the peel removal equipment demonstrated on a substantial scale (one to two tons of raw fruit per hour) that peach halves can be peeled efficiently by the low water volume ("dry caustic") peeling process. The quality of the peeled fruit was as good or better than that of fruit from commercial peeling units as judged by experienced industry people.

The peeling losses measured for the experimental unit were slightly lower than the peeling losses determined by measurement of commercial peeling. The difference in peeling losses was not large enough to provide an economic incentive based on higher product yield as is the case for the new potato peeling process.

The major advantage for the new method for peach peeling results from the lower water volume requirement and the reduction in the strength of wastewater generated.

A detailed study of fresh water requirements for rinsing and characterization of wastewater was made only for peach half peeling for the reason

TABLE X

RESULTS OF SHORT DURATION PEELING EXPERIMENTS ON MIXED SIZE TILTON APRICOTS

Run No.*	6-22-2	6-22-3	6-23-1	6-23-2	6-23-3	6-26-1
NaOH Conc., %	25-30	25-30	25-30	25-30	25-30	25-30
NaOH Temp. °F	210	210	210	210	210	210
Peeler Slope, In./10 ft	8	8	15	15	15	8
Feed, lb	30	30	45	60	30	45
Feed Time, Sec.	120	120	120	60	40	40
Feed Rate, lb/hr	900	900	1350	3600	2700	2330
Peeled Weight, lb	26.3	26.7	40.8	57.1	28.4	41.3
Washed Weight, lb	26.2	26.2	40.5	53.8	26.7	40.7
Total Peel Loss, %	12.6	12.6	10.0	10.3	11.0	9.5
Disk Spacing, in.	3/4	3/4	3/4	3/4	3/4	1/2
Gears Used	D**	D	D	D	S***	S
Peeled Fruit Quality	Good	Good	Good	Good	Good	Good
Rinse Water, gal.	5.0	5.0	5.0	5.0	5.0	5.0
Rinse Water, gal./ton	333	333	222	167	333	222
NaOH Dip Time, Sec.	30	30	22	22	22	30

Run No.	6-26-2	6-26-3	6-26-4	6-30-1	6-30-2	7-1-1
NaOH Conc., %	25-30	25-30	25-30	12.2	11.5	10.8
NaOH Temp. °F	210	210	210	210	210	140
Peeler Slope, in./10 ft	16	16	16	16	16	16
Feed, lb.	45	45	45	60	60	60
Feed Time, Sec.	90	75	65	115	120	120
Feed Rate, lb./hr	1800	1920	2500	1875	1800	1800
Peeled Weight, lb	41.7	41.2	41.7	53.1	54.1	56.6
Washed Weight, lb	40.1	40.0	39.4	53.0	53.2	N.R.
Total Peel Loss, %	7.3	8.4	7.1	11.5	9.8	N.R.
Disk Spacing, in.	1/2	1/2	1/2	1/2	1/2	1/2
Gears Used	S	1/2 D	D	D	D	D
Peeled Fruit Quality	Good	Good	Good	Good	Fair	Fair
Rinse Water, gal.	5	5	5	5	5	5
Rinse Water, gal./ton	222	238	222	166	167	167
NaOH Dip Time, Sec.	35	32	30	30	30	66

TABLE X (Cont'd.)

Run No.	7-1-2	7-1-3	7-1-4	7-1-5	7-7-1	7-7-2
NaOH Conc., %	11.1	10.8	10-11	11.5	11.0	11.2
NaOH Temp. °F	140	210	210	210	210	210
Peeler Slope, in./10 ft	16	16	16	16	16	16
Feed, lb	60	60	60	60	60	60
Feed Time, Sec.	120	120	120	120	68	68
Feed Rate, lb/hr	1800	1800	1800	1800	3200	3200
Peeled Weight, lb	54.5	55.2	55.0	55.5	55.3	55.9
Washed Weight, lb	54.3	N.R.	N.R.	53.8	N.R.	N.R.
Total Peel Loss, %	9.5	8.0	8.3	10.3	8.0	6.8
Disk Configuration	0	0	0	0	0	0
Disk Spacing, in.	1/2	1/2	1/2	1/2	3/4	3/4
Gears Used	D	D	D	D	D	D
Peeled Fruit Quality	Fair	Fair	Fair	Fair	Good	Good
Rinse Water, gal.	5	5	5	5	5	5
Rinse Water, gal./ton	167	167	167	167	166	166
NaOH Dip Time, Sec.	72	27	27	27	24	24

Run No.	7-9-1	7-9-2	7-9-3	7-9-4	7-10-1	7-10-2
NaOH Conc., %	9.8	10.0	9.8	10.8	10.0	10.0
NaOH Temp. °F	210	210	210	210	210	210
Peeler Slope, in./10 ft	16	16	16	16	16	16
Feed, lb	60	60	60	60	60	60
Feed Time, Sec.	68	68	68	68	68	68
Feed Rate, lb/hr	3200	3200	3200	3200	3200	3200
Peeled Weight, lb	55.9	56.2	57.8	57.6	55.3	55.0
Washed Weight, lb	N.R.	57.0	56.5	55.0	55.0	54.1
Total Peel Loss, %	6.8	6.3	5.9	7.5	8.3	9.3
Disk Configuration	0	0	0	0	0	0
Disk Spacing, in.	3/4	3/4	3/4	3/4	3/4	3/4
Gears Used	D	D	D	D	D	D
Peeled Fruit Quality	Good	Good	Good	Good	Good	Good
Rinse Water, gal.	5	5	5	5	5	5
Rinse Water, Gal./ton	166	166	166	166	166	166
NaOH Dip Time, Sec.	24	27	27	27	27	27

---

* The disk rotating speed was 373 RPM for all runs and the spindle sequence was F.

** S - Standard

*** D - Differential

N.R. - Not recorded

described above. The results of comparing commercial peeling and experimental peeling of peaches showed that the new peel removal method required only one-fifteenth of the fresh water used in conventional commercial peeling. The wastewater produced in the new peeling method was correspondingly reduced due to the use of mechanical abrasion for peel removal rather than water pressure. The strength of the wastewater from the experimental peeling of peaches was higher per unit volume than the wastewater from conventional chemical peeling. However, the much lower volume of wastewater produced per ton of fruit by the use of mechanical peel removal makes the lb of C.O.D. (and of B.O.D., although this was not measured directly) generated about one-third that of the conventional chemical peeling operation.

The numbers used to calculate values tabulated in Table XI are derived from Tables III and IV. The average of the two wastewater volumes and the average C.O.D. and S.S. of the two composite samples were used to calculate the values for the experimental peeler. The average values from Table IV were used to calculate figures for commercial peeling. The contribution of the effluent from the blancher wastewater shown in Figure 12 to volume, C.O.D. and SS was estimated as less than 0.5 percent of the total and was not corrected for in the calculation.

TABLE XI

COMPARISON OF WASTEWATER CHARACTERISTICS FOR COMMERCIAL AND EXPERIMENTAL PEELING OF CLING PEACH HALVES

WASTEWATER DISCHARGED
(PER TON PITTED PEACHES)

Peeler	Volume, gal.	C.O.D. lb	SS, lb
Commercial	527	59.5	10.4
Experimental	34.5	18.1	3.0

A comparison of water usage and wastewater characteristics in commercial and experimental peeling of peach halves are tabulated in Table XI.

Pre-Treatment of Unpeeled Pears

Several treatments of unpeeled pears before the application of sodium hydroxide solution were investigated to improve peeling efficiency and to reduce peeling losses.

Dewaxing of whole pears by immersion in 2-propanol held at 165°F reduced the peeling loss, but the quality of the peeled fruit was poorer due to residual peel fragments. It was concluded that hot or cold dewaxing of pears did not improve peeling sufficiently to justify the extra operation which would be required.

In the final pear peeling experiments it was found that placing 1/4 in. stainless steel bars across the peeling tray parallel to the spindles wiped a substantial portion of softened flesh from the pear surfaces (see Figure 6). This modification of the peeler unit had considerable promise in diverting organic material coating peeled tree fruit from the wastewater to the solid residue fraction.

Peeling Losses

Peeling losses were determined for the experimental peel removal unit and a commercial unit for each of the three fruits studied. The data collected during the peeling loss determinations are tabulated as ranges of values in Table XII.

TABLE XII

PEELING LOSSES FOR TREE FRUIT

Commodity	Peeling Loss, Percent Experimental	Commercial
Apricots	3.7 - 8.3	6.4 - 9.3
Peaches	5.3 - 7.5	5.5 - 8.0
Pears	11 - 20	12 - 15

Cost Estimate

The next logical step in demonstrating the utility of "dry caustic" peeling of tree fruit would be a five fold scale up to a unit with a capacity of about 10 tons of fruit per hour. The estimated capital cost of the peel removal section of a 10 ton per hour capacity unit is $16,000.

ACKNOWLEDGMENTS

The collaboration in this project by Gerald S. Williams, and others of the Engineering and Development Laboratory, Western Utilization Research and Development Division, Agriculture Research Service, United States Department of Agriculture, was instrumental in developing the results reported.

The cooperation, interest and assistance of many individuals associated with the canning industry is gratefully acknowledged; we especially thank E. L. Mitchell, W. L. Doucett, Ernest Johnson, R. Lovelace, S. Platou, S. M. Anderson, R. Ketcher, and L. K. Taber.

We appreciate the advice offered by Kenneth A. Dostal of WQO of EPA during this project and especially for help in preparation of reports.

Reference to a company or product name does not imply approval or recommendation of the product by the Environmental Protection Agency or by the Department of Agriculture and does not imply that there are no other suitable products available commercially.

REFERENCES

Anon. 1958. ASTM Standard Methods, Part 9, page 1303. Tentative Method for Indentation of Rubber by Means of a Durometer.

Anon., Preliminary Data, National Canners Association, 1970. Food Canning Wastes

Dostal, K.A., 1969. Secondary Treatment of Potato Processing Wastes, Final Report, Report No. FR-7, U.S. Department of the Interior, FWPCA NW Region, Pacific Northwest Water Laboratory, Corvallis, Oregon 97330, July.

Hart, M.R., R.P. Graham, C.C. Huxsoll and G.S. Williams 1970, An Experimental Dry Caustic Peeler for Cling Peaches and Other Fruit. 30th Annual Meeting, Institute of Food Technologists, San Francisco, California, May 25, 1970, Paper No. 59; J. Food Sci. 35 (6), 839-41 (1970)

Graham, R.P., Huxsoll, C.C., Hart, M.R., Weaver, M.L., and Morgan, A.I., Jr. 1969 "Dry" Caustic Peeling of Potatoes, Food Technology 23 (2), 61-66.

Graham, R.P., 1970, Proceedings, National Symposium on Food Processing Wastes, Portland, Oregon, April, pages 355-358.

Mercer, W.A., Rose, W.W., and Doyle, E.S., 1965. Physical and chemical characterization of the fresh water intake, separate in-plant waste streams and composite waste flows originating in a cannery processing peaches and tomatoes, Res. Report No. D-1612, prepared for the State of California Water Quality Control Board (March).

Smith, T., 1970, Proceedings, National Symposium on Food Processing Wastes, Portland, Oregon, April, pages 359-361.

Spicher, P.G., F.J. Agardy and G.T. Orlob, Proc. 22nd Ind. Waste Conference, 1967, Part I., page 44, Purdue University, Lafayette, Indiana.

PRODUCTION OF POTATO STARCH WITHOUT WASTE

by

Roy Shaw*, & W. C. Shuey**

ABSTRACT

The use of fine grinding and air classification of deydrated potatoes with sieving and minimum washing to produce potato starch is described. A substantial reduction in the amount of waste water over that required by conventional wet milling procedures was obtained. The procedure proposed would reduce wastes by 90 percent.

INTRODUCTION

This paper reports on investigations of potato starch production employing air classification technology, and on refinement of the starch fraction by carefully controlled washing. Utilization of the small amount of waste water was also considered.

Potato starch is traditionally produced by wet-milling, which requires large amounts of water to separate proteins, pulp, and other materials from the product. Olson(1) reported that, in a plant which utilizes 250 tons/day, the waste water was 800 gals/ton, excluding water for washing potatoes. In a modern plant in Europe, Caransa(2), with the newest processing equipment, predicted needing 792 gals/metric ton. Disposal of this waste water becomes difficult since Federal and State laws prohibit disposal in water courses, and disposal through municipal sewage plants would be expensive. Due to the low concentration of solids in waste water (1 percent according to Heisler(3), Olson(1), and deKoe(4)), little had been done towards recovery of components until the recent work of Heisler et al(3).

Since the mid-1950's, air-classifiers have become important devices for separation of flour by particle size and density (Graham(5)). The fine grinders and classifiers described by Behrens(6) effectively separated flour into fractions having varying protein contents. Gracza(7) defined this change in protein content of flour fractions as degree of protein

---

*Red River Valley Potato Processing Laboratory, East Grand Forks, Minnesota. Cooperatively operated by the Eastern Marketing and Nutrition Research Division, Agricultural Research Service, U. S. Department of Agriculture; Minnesota Agricultural Experiment Station; North Dakota Agricultural Experiment Station; and the Red River Valley Potato Growers' Association.

**Plant Science Division, ARS, USDA, North Dakota State University, Fargo, North Dakota. Cooperative investigations with the Department of Cereal Chemistry and Technology, North Dakota State University, Fargo, North Dakota. Published with the approval of the Director of the Agricultural Experiment Station, North Dakota State University, Fargo, North Dakota as Journal Series No.____.

Preceding page blank

shift. Peplinski et al(8) demonstrated that physical characteristics of wheat classes and variety influence this protein shift. Kent(9) showed that changes in moisture content of wheat or flour also appreciably altered the effectiveness of the protein shift. The number of fractions obtained was dependent upon the complexity of the flow employed in making the separations.

If finely ground, dehydrated potatoes have properties similar to those of wheat flour, perhaps the product could be separated into a "protein fraction" (suitable for animal feed) and a "starch fraction". If the starch fraction thus produced was not of commercial quality, it could be washed under careful conditions to minimize the amount of water used.

The concentration of solids in this wash water might be high enough that drying would be economical, thereby eliminating the waste problem; or recovery of valuable components by such processes as ion exchange could make production of potato starch more economical. Even if neither alternative was attractive, the amount of waste for disposal would be greatly reduced over present practices.

MATERIALS AND METHODS

The test potatoes were from sound, washed, random lots of various varieties which had been stored at 10-19°C. They were cut, dipped in 0.1 percent $NaHSO_3$ solution and dried as described in each experiment.

The dried samples were ground on an Alpine Pin Mill, Type 160, Alpine American Corporation, Saxonville, Massachusetts.

Samples were classified on a Midroplex Spiral Classifier, Type 132MP, Alpine American Corporation, Saxonville, Massachusetts.

Total Sugars. Determined by the Anthrone Method of Ashwell et al(10).

Reducing Sugars. Determined by a modified Nelson-Somogyi Method(11).

Starch. Sample was refluxed for 2.5 hours in 10 percent HCl followed by neutralization and by determination of reducing sugars, from which values for the previously determined total sugars were subtracted. A sample of pure potato starch similarly treated was used as a standard.

Protein. AOAC 9th Edition. Protein as measured by micro-Kjeldahl nitrogen x 6.25 was selected as a criterion of cleanliness; it being less soluble than sugars, amino acids, organic acids, etc.

Moisture. Determined by overnight drying in a vacuum oven at 32°C.

Agtron Color. Determined on an Agtron M-500 00/0-97/100, Magnuson Engineers, Inc., San Jose, California.

Gelatinization. The Brabender Amylograph was employed in studying the gelatinization properties of the different potato starches. A 20g.

sample of starch (dry basis) in 450 ml. distilled water was used for the determination. The temperature on the amylograph was programmed from 25-95°C., increasing at the rate of 1 1/2° per minute. The temperature was then held at 95° for 15 minutes and was followed by controlled cooling to 50°. The initial temperature of gelatinization, peak height, 15-minute-hold height, and 50° peak height were recorded.

RESULTS AND DISCUSSION

Fine Grinding and Air Classification

An initial experiment was conducted by using potatoes which had been dried at 85° and coarse ground on a pin mill at 9,000 RPM. The ground potatoes were then classified and the coarse fraction or "starch fraction" was reground in the pin mill at 19,000 RPM and classified. This initial study showed that a significant shift in protein content had been obtained by such a technique, and that, similar to wheat flour, potatoes could be air classified after fine grinding.

The second experiment was conducted to obtain a protein profile-air classification fractionation curve. The potatoes were dried at 85° and then run in the pin mill at 19,000 RPM. After each classification, the starch fraction was recycled through the classifier with minor changes of equipment settings.

Table 2 shows that potatoes are affected somewhat as is wheat flour (Pfeifer and Griffin)(13). There is a "protein fraction" that can easily be separated from a "starch fraction" and, as with wheat flour, continual reclassification of the starch fraction improves separation only up to a point. It appears (Table 1) that it would be impossible to produce a starch fraction of less than 4 percent residual protein by air classification alone.

Table 1 Results from Initial Study of Air-Classified Whole Potatoes

Sample	Grind RPM	Classifier Settings Feed Gate	Classifier Settings Fin Setting	Classified Fraction	Percent of Product	Protein Content %	Moisture Content %
Control		-	-	-	100	8.5	4.7
1st cycle	9,000	15	10°	Protein	8.8	15.2	4.3
				Starch	91.2	6.8	3.9
2nd cycle	19,000	15	10°	Protein	4.2	22.4	2.7
				Starch	95.8	6.3	4.9

Table 2 Effect of Reclassifying Starch Fraction

Cycle	Classifier Settings Feed Gate	Classifier Settings Fin Settings	Classified Fraction	Pounds Weight	Percent Protein Content	Percent Starch Content	Percent Sugar Content	Percent Moisture Content	Percent Others
0	-	-	Control	50	7.9	79.6	.8	1.3	10.4
1	15	10°	Protein	2.3	30.0	30.6	1.7	1.3	36.4
			Starch	46.3	5.8	83.7	1.0	1.7	17.8
2	15	15°	Protein	1.7	18.1	61.8	1.3	2.2	16.6
			Starch	44.0	5.4	82.9	.9	1.3	9.5
3	15	25°	Protein	6.1	8.2	76.3	1.0	1.2	13.3
			Starch	37.3	5.3	83.6	.9	2.0	8.2
4	15	35°	Protein	21.1	5.6	76.1	.8	1.7	15.8
			Starch	15.1	5.0	82.9	.9	2.8	8.4
5	10	38°	Protein	7.3	5.3	81.9	.9	2.2	9.7
			Starch	7.6	5.2	80.1	.7	1.7	12.3

Visual inspection of the fifth cycle starch fraction showed it to be enriched in coarse brown particles. A simple screening test indicated that most of these brown particles were retained on a 125-micron screen.

A third experiment was conducted to determine the effect of separating the ground potatoes into two fractions, first by sieving and then by additional fine grinding of the coarse, starch fraction after air classification. For this, potatoes were dried at 60°, ground, and then pin-milled at 14,000 RPM. Sieving over a 125-micron screen separated the groundmaterial into two fractions. Material remaining on the screen was principally coarse, brown peel fragments. That which passed through the screen was air classified. The starch fraction of the first cycle was reground at 19,000 RPM and again classified.

Sieving to remove brown peel and fibre fragments before classification significantly lowered the residual protein in the starch fraction as shown in Table 3.

A sample of blanched, dehydrated diced potatoes was obtained from a local source for a fourth experiment to determine if blanching would affect the protein-shifting potential. The data indicated that even cooked potatoes exhibit some protein shifting when fine ground and classified.

A fifth experiment was conducted to determine the effect moisture content might have on air classification of potatoes and on protein shift. Potatoes were dried at 60° and run through the pin mill at 14,000 RPM. Material passing through 125-micron screening was exposed as a thin layer to high humidity overnight. This "high moisture" material was classified, the "first cycle starch fraction" being reground at 19,000 RPM and again classified.

Moisture as high as 11 percent does not materially affect air classification of finely ground potatoes.

A sixth experiment was performed to determine the effect of drying temperature upon air classification of the potatoes. About one-half of the potatoes were dried at 82°, the rest being dried at 121°; all were run through the pin mill at 14,000 RPM. Material passing through a 149-micron screen was exposed to high humidity and classified. The starch fraction was reground at 19,000 RPM and again classified. The feed rate to the classifier was varied in the second cycle of each run.

The initial drying temperature does not affect classification. The darker color as reflected by Agtron color (Table 4 and Table 5) indicates some heat damage, as one would expect. The potatoes were hard and vitreous after drying at 121°, and did not grind easily; thus, the preliminary screening was done on a 149-micron screen.

Purification of Starch Fractionation

Previous experiments showed that the starch fraction should be washed in order to make a commercially acceptable product with less than 1 percent protein. Figure 1 outlines a typical procedure in the reusing of wash water in a counter-current fashion.

Table 3 Effect of Preliminary Sieving before Classification

Cycle	Grind RPM	Classifier Settings Feed Gate	 Fin Setting	Classified Fraction	Pounds Weight	Percent Protein Content	Percent Starch Content	Percent Sugar Content	Percent Moisture Content	Percent Other
0	14,000	-	-	+125 micron	1.3	8.7	75.7	1.2	3.3	11.1
				-125 micron	25.8	6.9	80.1	0.7	2.5	9.8
1	14,000	15	25°	Protein	2.8	18.5	44.0	1.3	3.6	32.6
				Starch	22.8	4.9	82.7	0.5	3.1	8.8
2	19,000	15	25°	Protein	3.3	11.6	71.6	1.3	4.3	11.2
				Starch	18.3	4.0	86.1	0.4	2.7	6.8

Table 4 Effect of High Moisture on Air Classification of Potatoes

Cycle	Grind RPM	Classifier Settings Feed Gate	 Fin Setting	Classified Product	Pounds Weight	Percent Protein Content	Percent Moisture Content	Agtron Color
0	14,000	-	-	Starting	24.0	8.0	11.4	82.5
1	14,000	15	25°	Protein	2.5	17.1	7.2	81.7
				Starch	21.0	4.7	10.9	86.7
2	19,000	15	25°	Protein	2.0	11.9	6.9	84.8
				Starch	17.3	4.5	8.2	90.8

Table 5 Effect of Drying at 82°C. and 121°C. on Classification of Potatoes

Cycle	Grind RPM	Classifier Settings		Classified Product	Pounds Weight	Percent Protein Content	Percent Moisture Content	Agtron Color
		Feed Gate	Fin Setting					
				DRIED AT 82°C.				
0	14,000	-	-	Starting	26.3	6.8	6.6	77.0
1	14,000	15	25°	Protein	4.5	14.2	5.1	79.5
				Starch	21.5	5.1	7.7	79.8
2	19,000	10	25°	Protein	2.3	12.7	4.3	79.8
				Starch	18.3	4.4	6.1	84.9
				DRIED AT 121°C.				
0	14,000	-	-	Starting	25.0	6.6	4.6	64.9
1	14,000	15	25°	Protein	3.0	14.1	3.4	70.2
				Starch	21.8	5.7	4.8	64.6
2	19,000	20	25°	Protein	3.8	10.7	3.6	75.9
				Starch	17.3	5.0	4.1	72.8

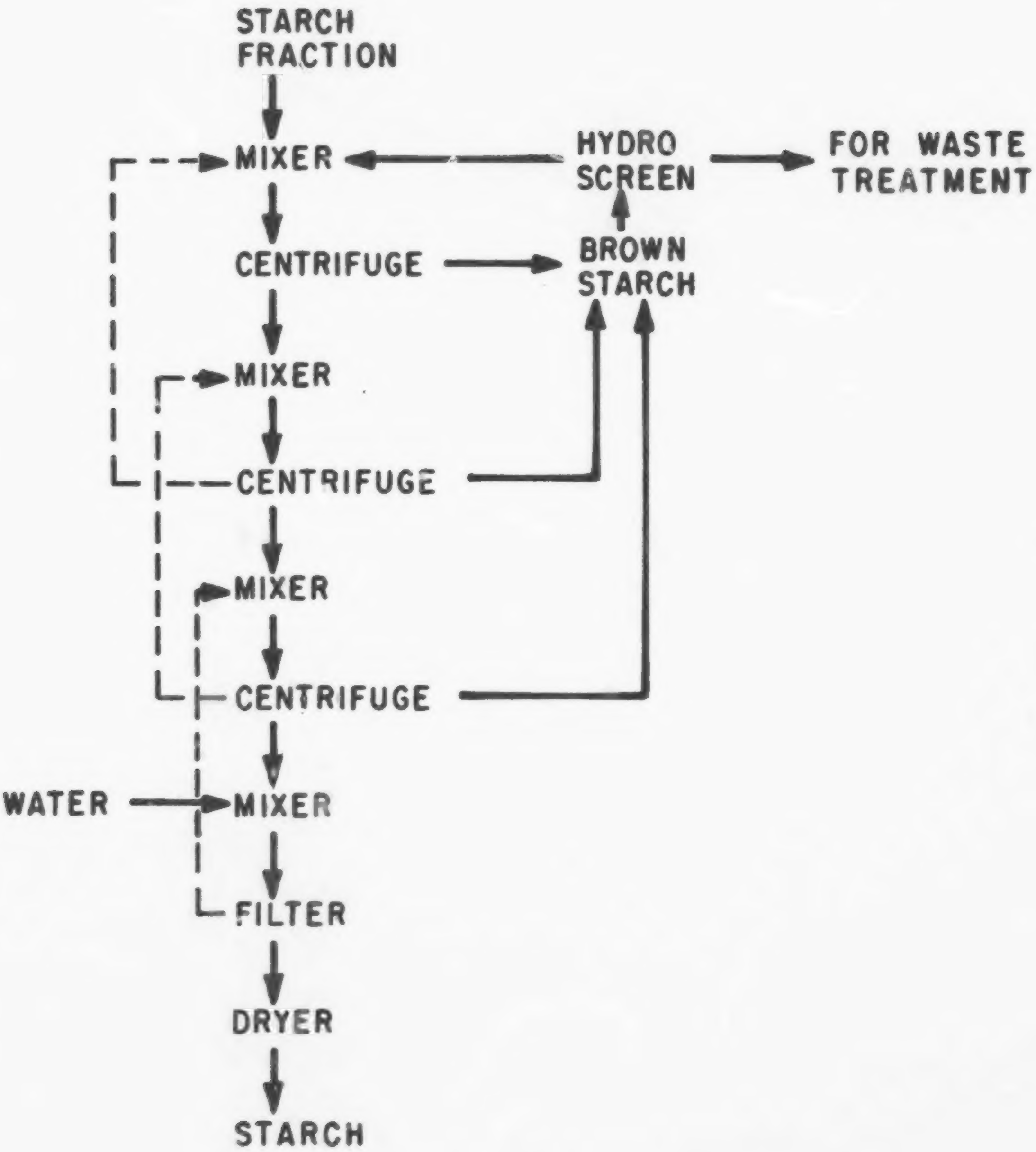


Figure 1. Production of Potato Starch Without Waste

Initial mixing required 3 parts of liquid to 1 part of starch fraction, while subsequent steps required 2 parts of liquid. Material in the brown starch tank contained white starch and pulp as well as dissolved solids. This "brown starch" liquid was screened in such a fashion that the white starch and half the liquid was returned to the system, the pulp and remaining liquid being withdrawn. The amounts of protein in the washed starch and solids in the wash liquid were determined at each step. Typical data are presented in Table 6.

Table 6 Typical Analysis of Protein in Washed Starch and Solids in Wash Water in Countercurrent Washing

	Protein	Solids in Washwater
	Percent	Percent
4th washing	.99	.2
3rd washing	1.07	1.0
2nd washing	1.48	2.9
1st washing	1.98	9.1
Initial	4.5	

In another experiment the final wash water had a total solids concentration of 10.85 percent. The analysis of these solids is presented in Table 7.

Table 7 Analysis of Solids in Final Wash Water

Total Solids	10.85%
Protein (Kjeldahl X 6.25)	28.5
Protein (Biuret Reagent)	(4.6)
Free Amino Compounds (as asparagine using Stein-Moore Reagent)	(20.4)
Amino Compounds Automatic Amino Analyser	(18.8)
Total Reducing Sugars	12.4
Total Organic Acid	35.4
Potassium (Flame Photometer)	17.7

The starch fractions of material dried at 82° and 121° were similarly washed (Table 5). That from the higher drying temperature contained a partially gelatinized material which required 5 volumes of water to make into a workable slurry. The gelatinous material was removed with the brown starch.

Brabender amylograph curves were calculated to determine if the starch had been heat-damaged and are shown in Figure 2. The temperature of initial gelatinization was essentially the same for all of the starches except the commercial. This starch had a slightly higher initial temperature of gelatinization. From an examination of Figure 2 it can also be observed that the commercial starch granules swell more readily than do those of the other starches. The highest peak was obtained from starch dried at 82° and the lowest point was obtained from the Grafton commercial starch. Variations in peak height amongst the different starches were observed. A definite breakdown was observed for all of the starches during the 95° hold period although the breakdown was not the same in all cases. Likewise, the height at 50° varied somewhat for the different starches.

An experiment was designed to maximize yields of starch and to determine the efficiency of a process employing fine grinding, air classification, sieving, and washing. Data obtained from previous experiments indicated that, with the proper combination of the various treatments, it was possible to obtain an acceptable potato starch that would require considerably less wash water for removal of protein and other solids.

The potatoes were dehydrated at 60° and put through the pin mill at 19,000 RPM. Screening through an 88-micron screen best removed brown particles. Material passing through the 88-micron screen was classified and the starch fraction reclassified until 10-15 percent of the stream was removed as protein fraction.

Removal of some brown particles from the starch fraction was sieved with a 53-micron screen and 53/44-micron screening removed a small amount of inadequately ground particles. Normally, this 53/44 fraction would be reclaimed by recycling through the mill. The -44-micron material was used for starch washing steps.

The final, screened starch fraction was then washed by the counter-current procedure of Figure 1, including the recovery of white starch in the brown starch fraction. The recovered starch was dried and weighed. This experiment is summarized in Figure 3.

The final wash water of 10-11 percent solids represents a tenfold concentration over normal waste effluent of a conventional wet-milling potato starch plant, and thus a 90 percent reduction in volume of effluent. Such a waste effluent could be drum-dried. deKoe(4), working with 1 percent solids effluent from a European starch plant, recommended spray-drying after preconcentration. Effluent of 10-11 percent solids should further enhance his suggestion.

Strolle, et al(14) discussed de-proteinization of simulated starch waste prior to ion exchange and showed that increasing total solids from 1.5 percent to 2.8 percent significantly increased the efficiency of the protein removal necessary for ion-exchange. Increasing solids to 10-11 percnet should further increase efficiency of protein removal.

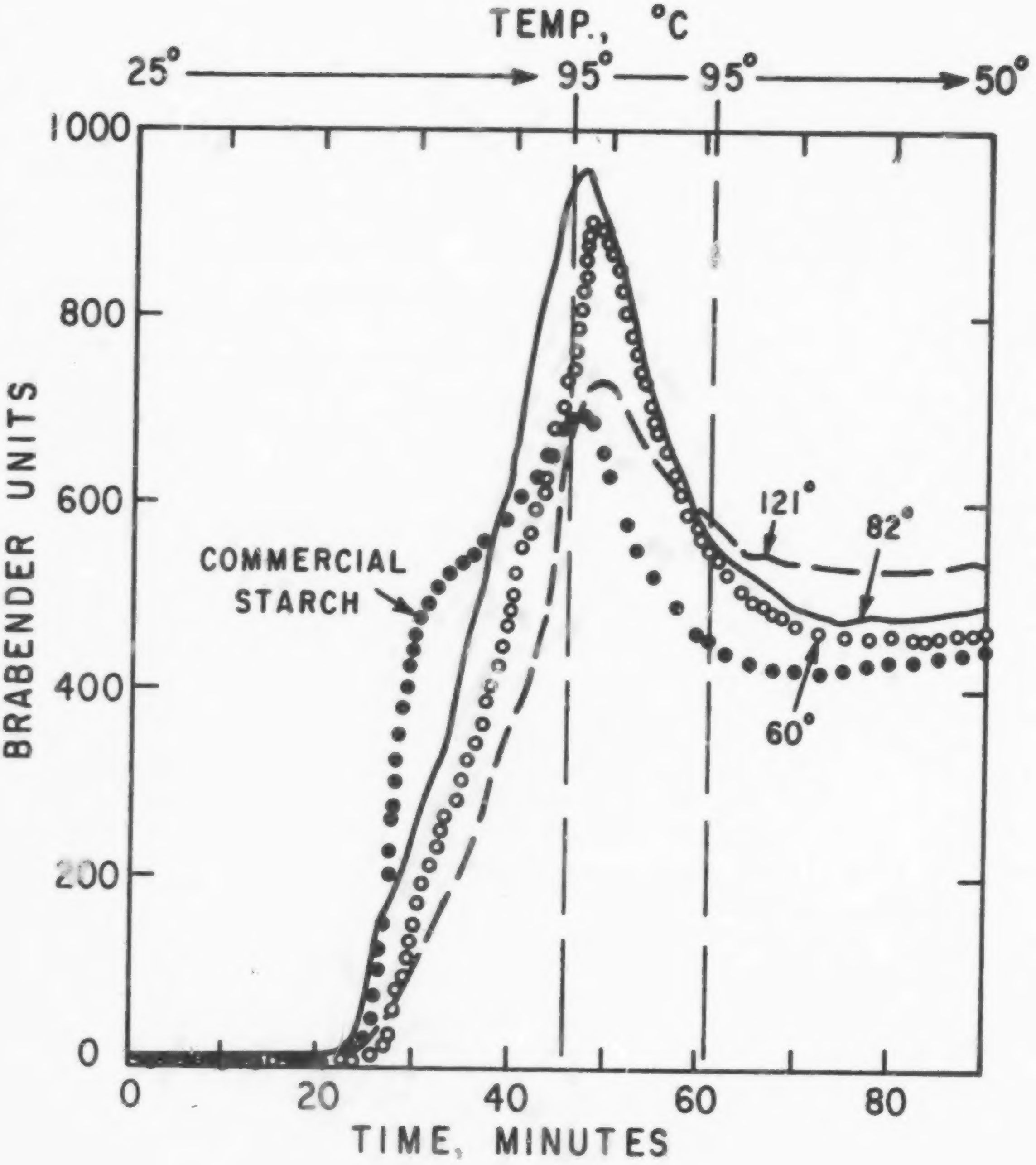


Figure 2. Production of Potato Starch Without Waste

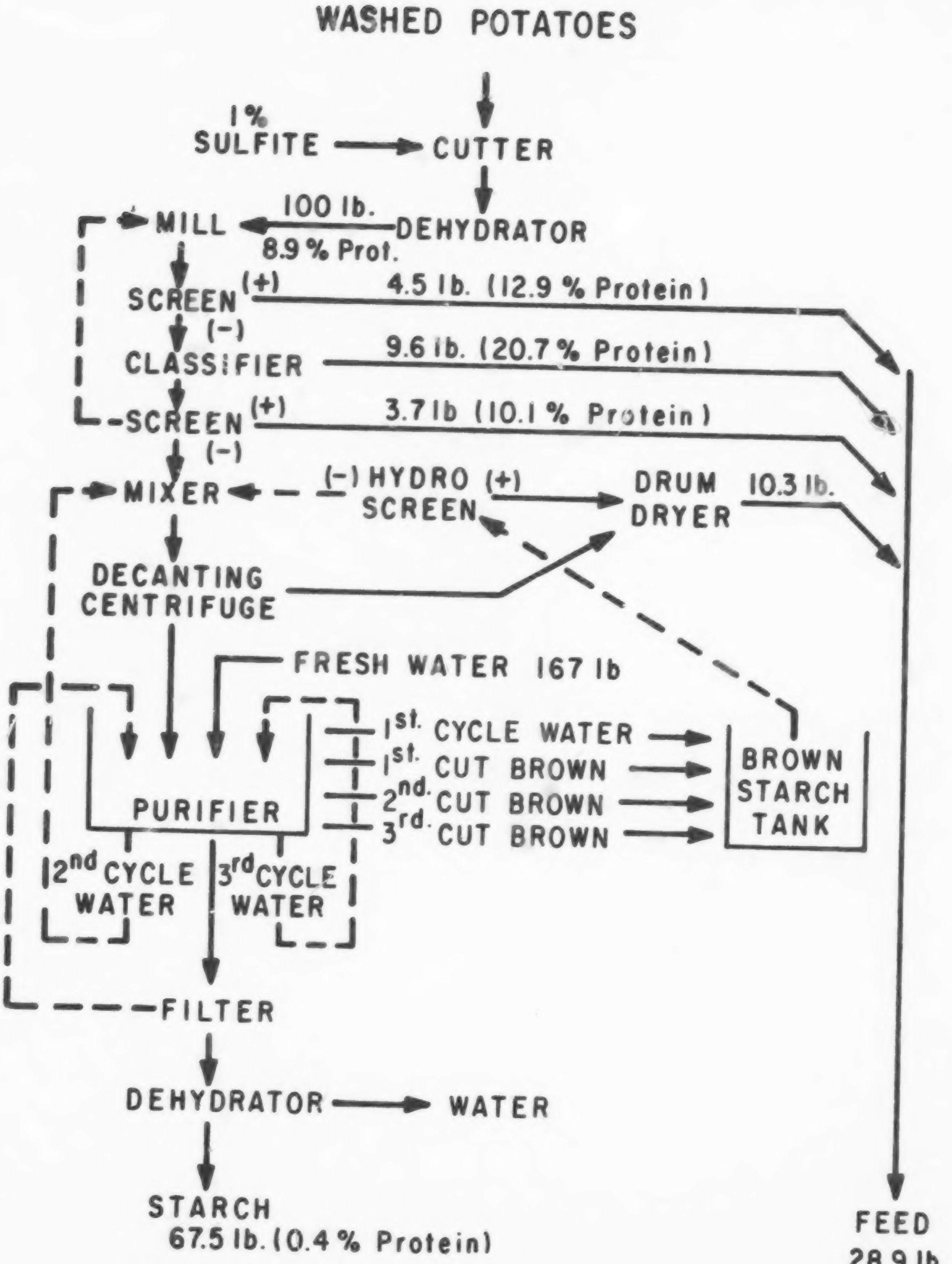


Figure 3. Production of Potato Starch Without Waste

CONCLUSION

On a laboratory scale, the process of drying, fine grinding, air classification, and washing can be fairly efficient. The unit processes are straightforward and use in a larger operation should be feasible.

Use of the drum dryer for wash-water drying would not involve a waste effluent. Alternately, the liquid could be added to previously separated protein fraction and redried in a pulp dryer. The animal feed fraction obtained from the process would have a protein content of 15-20 percent compared to the 6-8 percent protein in the dried potato pulp obtained from a conventional potato starch plant.

If recovery of valuable by-products by means of ion-exchange appears to be attractive, the amount of waste effluent for disposal would be only a fraction of that from a wet-grinding starch plant. Even without drying or ion-exchange, the volume of waste is only 10 percent and the quantity of solids only 40 percent that of a conventional plant.

LITERATURE CITED

1. OLSON, O. O., VAN HEUVELEN, W., and VENNES, J. W. Combined industrial and domestic waste treatment in waste stabilization lagoons. J. Water Pollution Control Federation 40: 214 (1968).

2. CARANSA, A. Von neue Erfahrungen mit Dorr-Oliver Multizyklonen und D-6 DSM Bogensleben in der Kartoffelstarke-Industrie. Die Starke 22: 27 (1970).

3. HEISLER, E. G., SICILIANO, J., TREADWAY, R. M., and WOODWARD, C. F. Recovery of free amino compounds from potato starch processing water by use of ion exchange. Amer. Potato J. 36: 1 (1959).

4. deKOE, W. J. Protein recovery from potato starch mill effluent. Water and Waste Treat. J. 12: 55 (1968).

5. GRAHAM, J. C. The use of air classifiers in the flour milling industry. Milling 144: 215 (1965).

6. BEHRENS, D. Neuere Fein-und Feinstaprailmuhlen. Die Muhle 100: 3 (1964).

7. GRACZA, R. The subsieve-size fractions of a soft wheat flour produced by air classification. Cereal Chem. 36: 465 (1959).

8. PEPLINSKI, A. J., BURBRIDGE, L. H., and PFEIFER, V. F. Air classification of leading varieties in U. S. wheat classes by standardized fractionation procedure. Amer. Miller and Processor 93: 7 (1965).

9. KENT, N. L. Effect of moisture content of wheat and flour on endosperm breakdown and protein displacement. Cereal Chem. 42: 125 (1965).

10. ASHWELL, G. Colorimetric analysis of sugars. In "Methods of Enzymology", Vol. 111, p. 73. S. P. Colowick and N. O. Kaplan, Eds., Academic Press, New York (1957).

11. NELSON, N. A photometric adaptation of the Somogyi method for determination of glucose. J. Biol. Chem. 153: 375 (1944).

12. ASSOC. OFFIC. AGR. CHEMISTS. Methods of analysis, 9th ed., 643: items 38.009 and 38.011 (1960).

13. PFEIFER, V. F. and GRIFFIN, E. L., JR. Fractionation of soft and hard wheat flours by fine grinding and air classification. Amer. Miller and Processor 88: 15 (1960).

14. STROLLE, E. O., CORDING, J., JR., ACETO, N. C. and DELLA MONICA, E. S. Recovering proteins from potato starch factory effluents. Presented at the 20th Natl. Potato Utiliz. Conf., Riverside, Calif., July 31, 1970.

ACKNOWLEDGMENTS

We thank Dr. B. D'Appalonia, North Dakota State University, for the starch amylograms; Mr. E. G. Heisler, Research Chemist, Eastern Marketing and Nutrition Research Division, Philadelphia, Pennsylvania, for analysis of waste water; and Messrs. R. Maneval, Crops Research Division, ARS, U.S.D.A., Fargo, North Dakota, and Gerald A. Baumann, Red River Valley Potato Processing Laboratory, East Grand Forks, Minnesota, for technical assistance.

ECONOMIC ANALYSIS OF ALTERNATIVE METHODS FOR PROCESSING POTATO STARCH PLANT EFFLUENTS

by

R. L. Stabile, V. A. Turkot and N C. Aceto*

ABSTRACT

The results of a preliminary economic analysis of alternative methods of treating potato starch plant waste effluent in order to conform to present government pollution regulations are presented. The alternatives discussed consist of one biological treatment method and four methods involving recovery of one or more by-products. All of the alternatives involve considerable capital investment and operating costs. The only alternative that appears economically feasible at this time is concentration of the protein (or fruit) water by multistage evaporation and use of the concentrate in animal feed.

SUMMARY

Potato starch processing plants must now treat their waste water effluents beyond primary treatment in order to conform to government regulations on pollution concentration limits and water quality. Meeting these regulations requires considerable capital investment and considerably increased operating costs as a result of the installation of equipment and facilities needed to treat the waste water for removal of pollutants. Preliminary capital and operating cost estimates were made on five possible alternatives in order to determine which were economically feasible and worthy of further study. The alternatives included one conventional type biological treatment method plus four processes yielding by-products, as follows: 1. biological treatment, 2. protein recovery with biological treatment, 3. concentration by evaporation, 4. protein recovery and concentration of protein-free waste, 5. protein recovery, ion-exchange and biological treatment. The estimates were based, in part, on laboratory and pilot plant data for Alternatives 2, 3, 4 and 5; Alternative 1 was based on data from the literature. Only one alternative - concentration of the protein water by multistage evaporation - appears commercially feasible at this time. The concentrate would be used in cattle or poultry feed. This process is under futher study at our Laboratory, and the results of that study will be published.

---

*Eastern Regional Research Laboratory, Agricultural Research Service, U. S. Department of Agriculture, Philadelphia, Pennsylvania.

Preceding page blank

INTRODUCTION

The present requirements for the limits of pollutants in processing plant waste water are necessary in order to preserve what is considered good water quality for natural streams. The effect of these requirements on potato starch plant operations is to place an economic burden on an industry which is already only marginally profitable. In present starch-making technology, practically all of the soluble components of the potato are released into the plant waste water. This yields an effluent which has both a high BOD level and a large daily flow. These two characteristics result in high sewage charges, that is, assuming the local sewage plant will accept the discharge at all. If the starch plant must build its own biological waste treatment plant, the costs - both capital and operating - will be substantial. An alternative method of treating the effluent is to recover the water-soluble constituents from the waste stream in usable form and sell them as by-products. However, since the waste stream is dilute, recovery processes will have high operating costs and require considerable capital investment in relation to existing starch plant valuation. Nevertheless, a by-product recovery process could be justified if the selling price for the product or products resulted in a reasonable return on investment.

A preliminary economic evaluation of several potential waste treatment processes was made in order to see if any were commercially feasible. Since little pilot plant data had been obtained, this evaluation was primarily to see which process or processes deserved further investigation on the pilot plant scale. The estimates are based on treating the waste water from a 30 ton per day starch plant operating 16 hours per day, 150 days per year. Five alternatives are compared. One alternative considers biological treatment of the waste with no recovery of the components of the waste as by-products. The other four alternatives involve recovery of waste components and yield one or more by-products. The waste stream was considered to come from a starch plant using current technology for starch recovery. The protein water waste flow used as a basis was approximately 104,000 gallons per day at a 2 percent by-weight dissolved solids concentration. This basis was considered an approximation of average starch plant operation using some improved water utilization.

Briefly, the five alternatives compared are: 1. biological treatment, 2. protein recovery with biological treatment, 3. concentration by evaporation, 4. protein recovery and concentration of protein-free waste, 5. protein recovery, ion-exchange and biological treatment. Let us look at the technology involved in each of the alternatives.

Alternative 1 Biological Treatment of Waste.

The treatment requirements for the waste treatment plant include at least 85 percent removal of BOD and suspended solids and complete removal of floatable and settleable solids. Other factors that must be considered for each plant location are the effect of the effluent discharge on the dissolved oxygen content of the receiving river or stream and the necessity for disinfection by chlorination. Chlorination is probably not required for starch plant waste treatment because pathogens are not present in the source of the waste.

The biological waste treatment process chosen is the activated sludge type. In this process, shown in Figure 1, the raw waste is screened to remove fibrous solids which are used as animal feed. The liquid containing suspended and dissolved solids is fed to the primary clarifier where settleable solids are removed. The solids removed from the primary clarifier are used in animal feed. The overflow from the primary clarifier goes to the aeration tank where biological degradation of the waste occurs. The effluent from the aeration tank is pumped to the secondary clarifier where the biologically active sludge is settled. Part of this sludge is returned to the aeration tank; the remainder passes to a digester where it is converted into gases and final solids by biological action. Final solids from the digester are assumed to be disposed of by land fill.

An activated sludge treatment system was selected because the design, operating procedures, and costs of this type system are well known, and also because it will consistently give high BOD removal.

The plant is assumed to process 625,000 gallons per day of waste water containing 11,320 lbs of BOD and 8,000 lbs of suspended solids. This total volume includes the combined protein water, wash waters from purifying the starch, and water used to flume and wash the raw potatoes. The treated waste sent to the river is approximately 600,000 gallons per day, containing 1,100 lbs of BOD and 1,000 lbs of suspended solids. Solids are removed from the screen and primary clarifier at a rate of about 5,000 lbs per day.

Alternative 2 Protein Recovery and Biological Treatment.

Protein recovery from protein water has been investigated by Strolle on a pilot plant scale(1). The results of this investigation were used to design a full scale plant. The process is shown in Figure 2. The protein water effluent from the starch plant is preheated, using the heated protein water from the steam injection heater, in a plate type exchanger. After preheating, sulfuric acid is added to an agitated tank which feeds the steam injection heater. The pH of the protein water is lowerd to approximately 3.5, and the exit temperature from the heater is 210°F. The precipitated proteins are removed from the slurry using a continuous rotary filter. The wet protein solids, containing about 87 percent water, are dried on a double drum dryer to about 5 percent moisture. The dried cake is ground and packed in 100 pound bags.

After de-proteinization the waste stream is sent to a biological treatment process for removal of 80 percent of the remaining BOD, to give a final BOD of about 1,100 lbs per day. The biological process would be the same as described under Alternative 1 except that incoming BOD would be reduced to 8,300 lbs per day because of the removal of the protein. Flow would be almost the same as Alternative 1, and there would be no suspended solids. Therefore, a lower cost would be incurred.

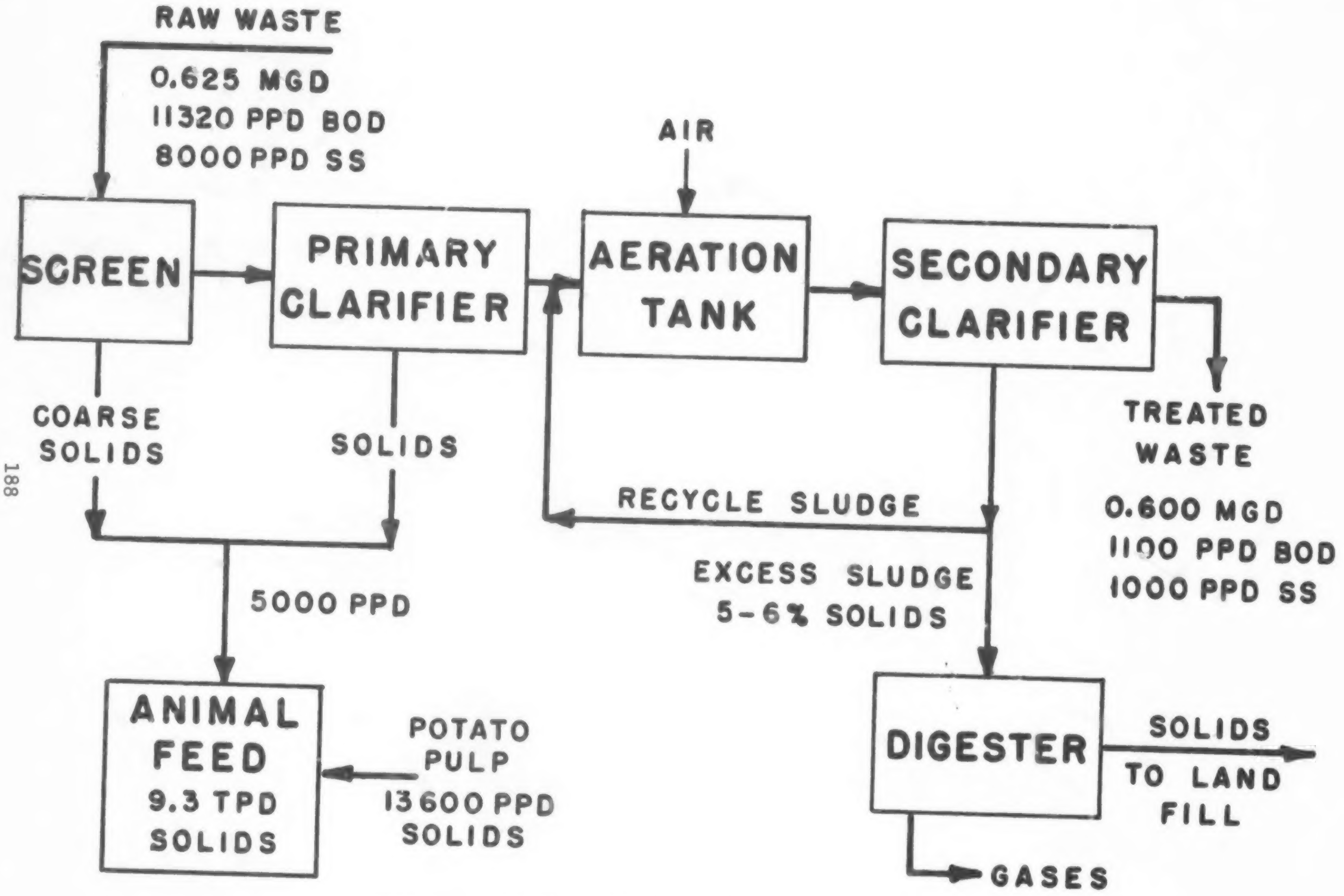


Figure 1. Activated Sludge System (Alternative 1).

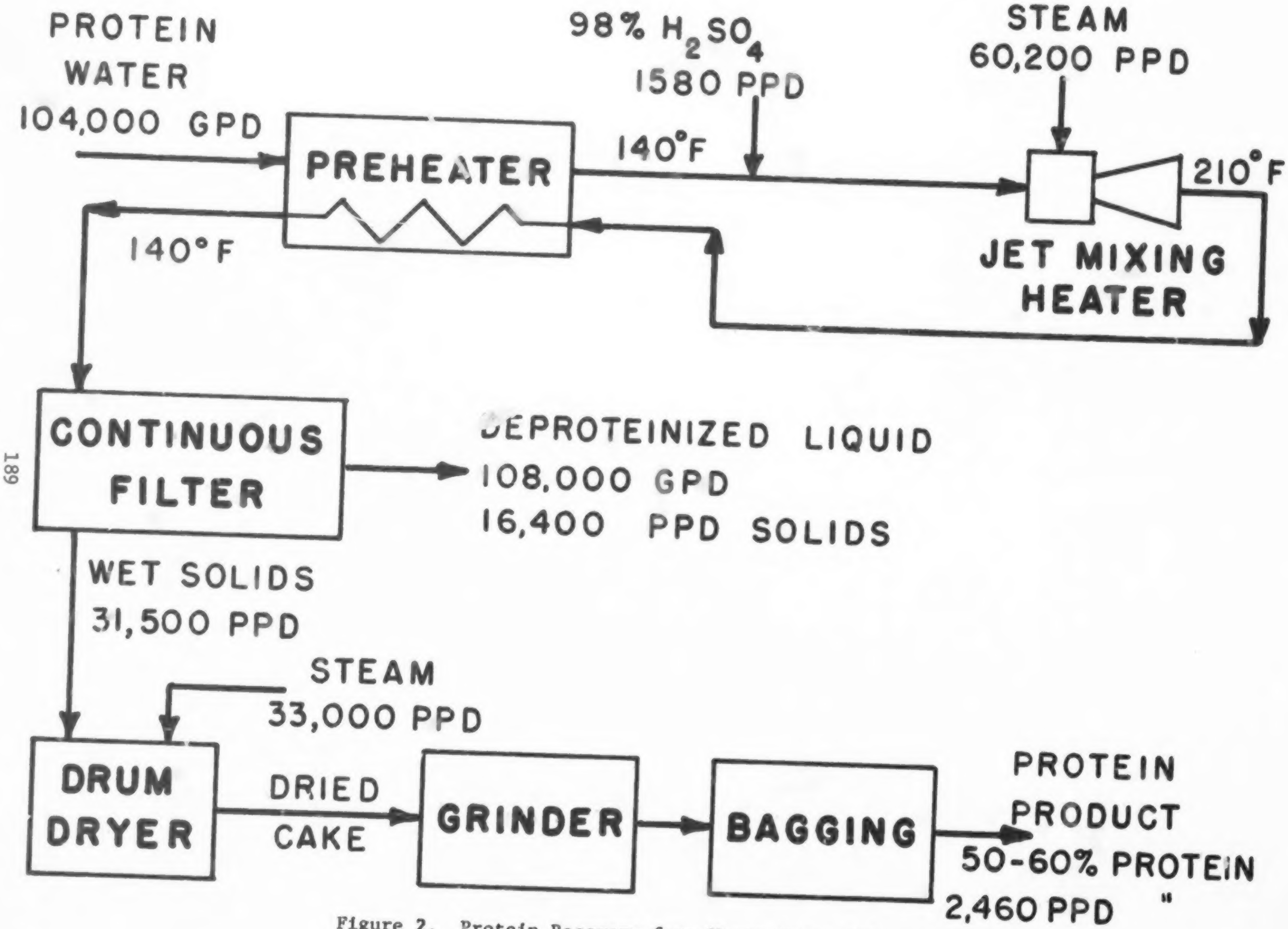


Figure 2. Protein Recovery from Waste Water (Alternative 2).

Alternative 3 Concentration by Evaporation

The basis for studying this process was to determine if it would be feasible to concentrate the entire protein water stream and make a profit by selling the concentrate for feed use.

The protein water is evaporated in a triple effect evaporator to a 60 percent solids slurry. The slurry is mixed with the dried potato pulp from the starch process and the mixture is sold as animal feed (Figure 3).

Approximately 320,000 pounds per day of steam would be required for the evaporation.

The capital and operating costs are based on the evaporation step only. The cost for pulp drying is considered to be recovered through the sales value of the pulp constituent in the mixed feed product.

Alternative 4 Protein Recovery and Concentration of Protein Free Waste.

This alternative was investigated because it was anticipated that a market might exist for both the protein and protein-free solids.

Figure 4 shows a schematic flow sheet of the process. The protein water goes first to the protein recovery process as described under Alternative 2. The de-proteinized liquid is evaporated in a triple effect evaporator as described under Alternative 3.

Alternative 5 Protein Recovery, Ion-Exchange and Biological Treatment.

This alternative consists of the combination of the protein recovery process already described under Alternative 2, an ion-exchange process which recovers potassium salts, amino acids and organic acids (both as ammonium salts), and the biological treatment process described under Alternative 1. Figure 5 shows these three sections of the process combined to form this alternative.

The protein water is first sent to the protein recovery process(1). It is necessary to remove the proteins first because they will precipitate on the ion-exchange columns if their concentration is 180 ppm or more.

After protein removal, the waste is treated by the ion-exchange columns which remove mainly potassium ions, amino acids and organic acids from the waste stream(3,4,5). A final biological treatment removes most of the remaining dissolved solids, which are chiefly sugars.

Figures 6, 7 and 8 are schematic flow sheets showing the processing involved in the ion-exchange part of this alternative. In each of the three sets of ion-exchange columns, two columns are in series at one time performing adsorption and one column is being eluted and regenerated. Also, each by-product solution resulting from ion-exchange is evaporated to 60 percent concentration before drum drying to 4 percent moisture. Figure 6 shows the potassium ion removal by cation exchangers and recovery of solids by evaporation. After absorption and elution with sulfuric acid, an acidic solution is obtained which is neutralized with ammonia. The potassium and ammonium sulfate solution is evaporated and dried yielding the mixed salt solid.

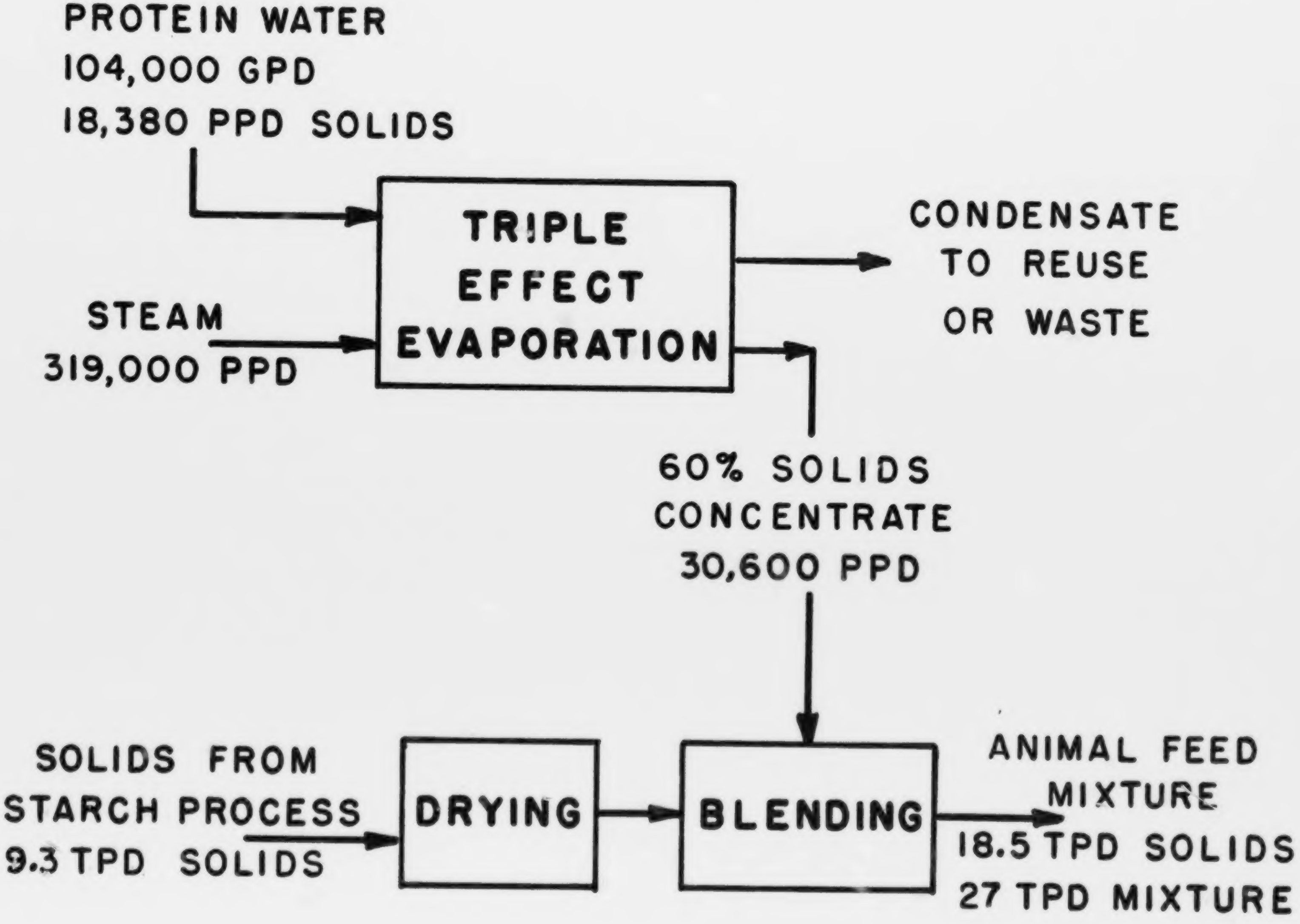


Figure 3. Protein Water Concentration by Evaporation (Alternative 3).

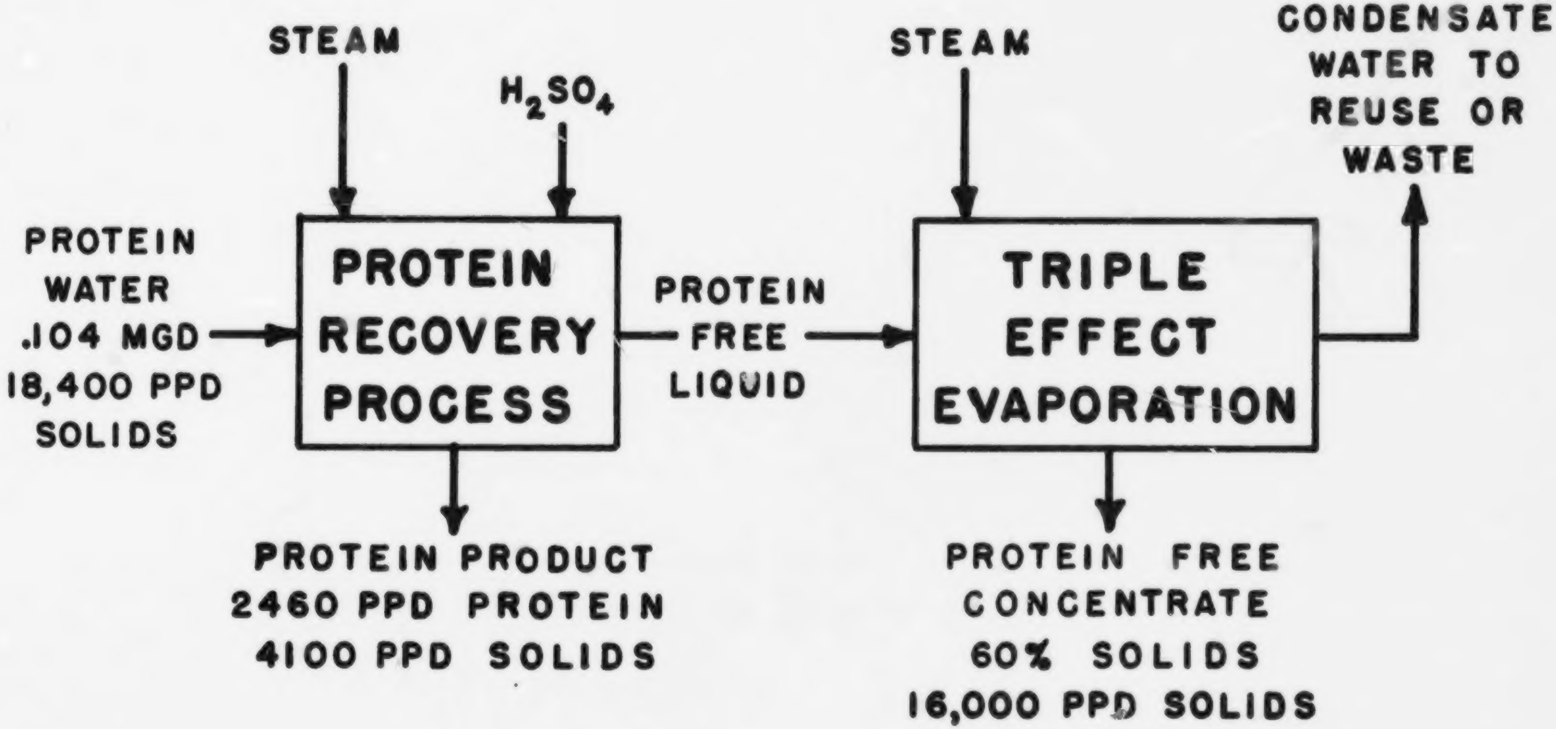

STEAM
H_2SO_4
STEAM
CONDENSATE WATER TO REUSE OR WASTE
PROTEIN WATER .104 MGD 18,400 PPD SOLIDS
PROTEIN RECOVERY PROCESS
PROTEIN FREE LIQUID
TRIPLE EFFECT EVAPORATION
PROTEIN PRODUCT 2460 PPD PROTEIN 4100 PPD SOLIDS
PROTEIN FREE CONCENTRATE 60% SOLIDS 16,000 PPD SOLIDS

Figure 4. Protein Recovery and Concentration of Protein-Free Waste (Alterative 4).

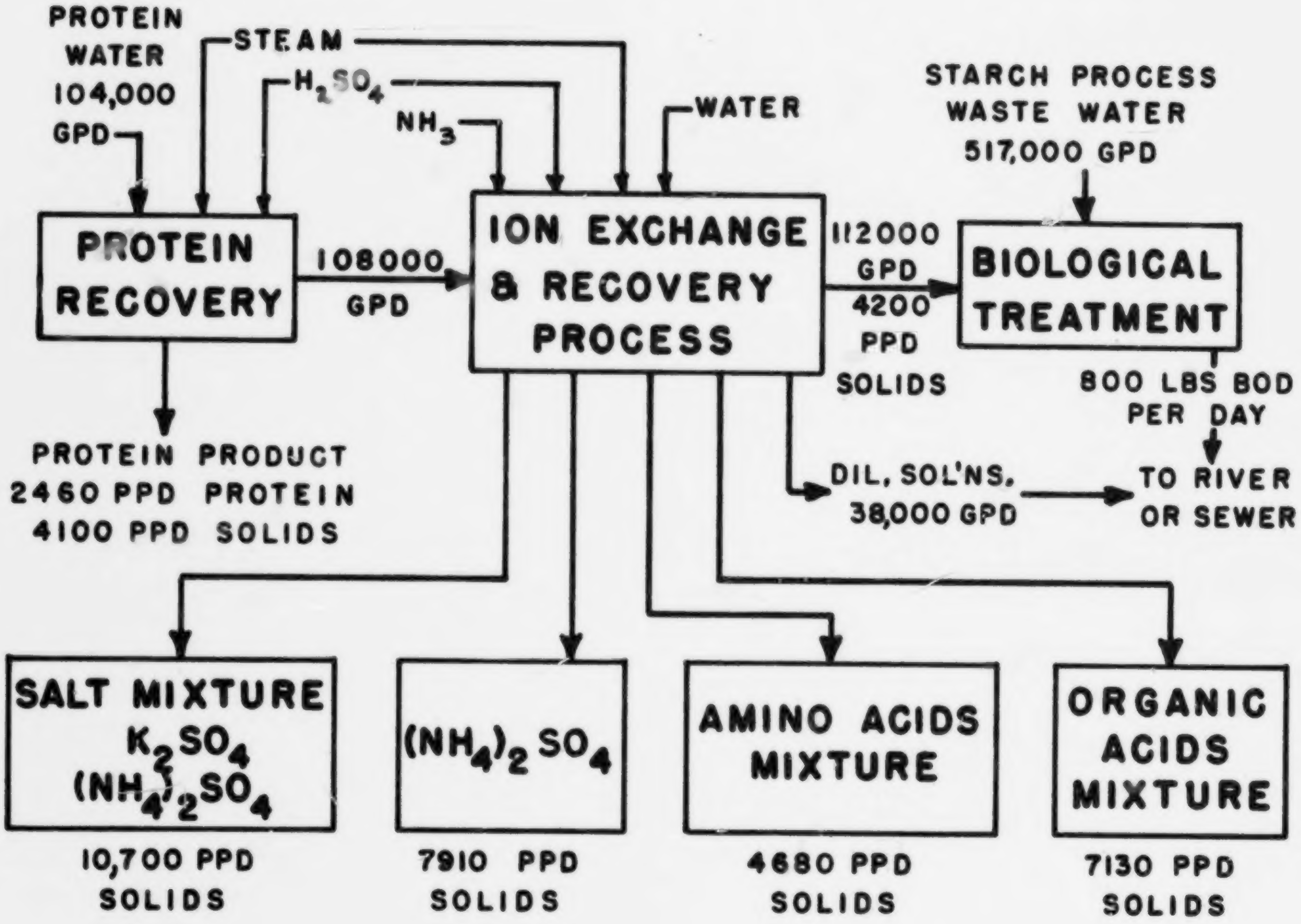


Figure 5. Protein Recovery. Ion Exchange. and Biological Treatment (Alternative 5).

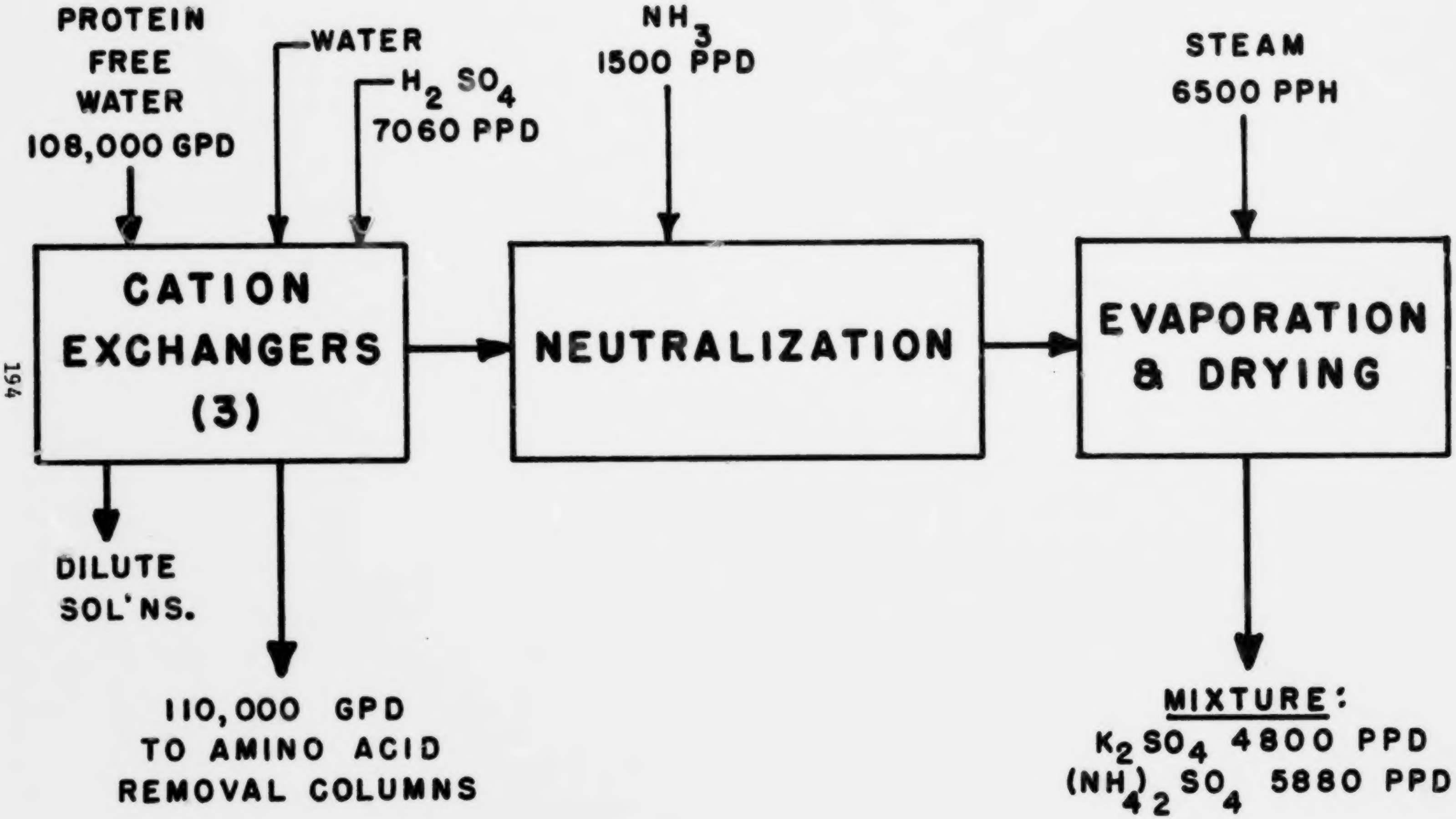


Figure 6. Potassium Ion Removal - Ion Exchange Process (Alternative 5).

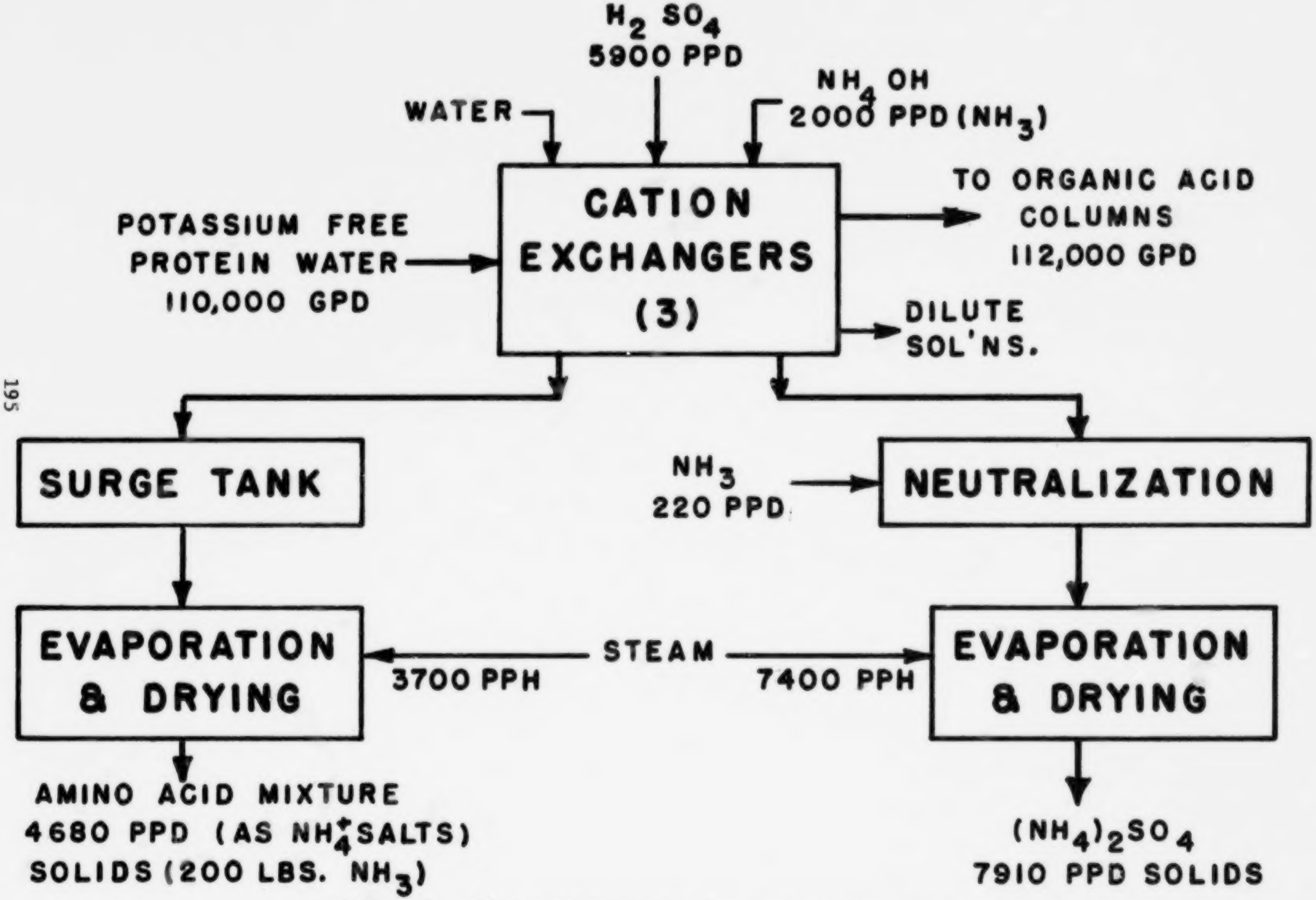


Figure 7. Amino Acid Removal - Ion Exchange Process (Alternative 5).

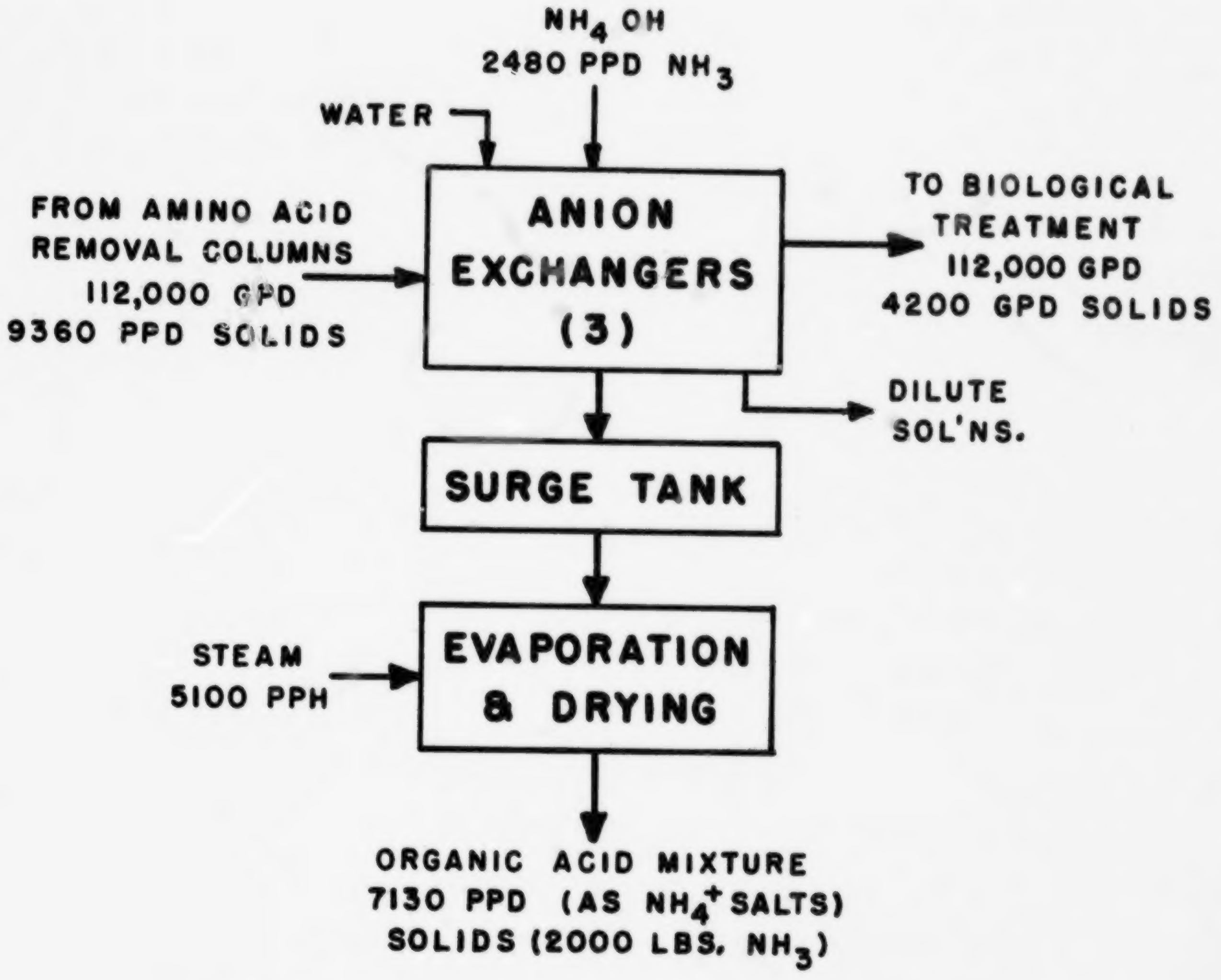


Figure 8. Organic Acid Removal - Ion Exchange Process (Alternative 5).

Figure 7 shows the amino acid removal from the potassium-free stream by cation exchangers. The adsorbed amino acids are eluted using ammonium hydroxide. The columns are regenerated with sulfuric acid. The amino acid and ammonium sulfate solutions are evaporated and dried. The amino acids are obtained as the ammonium salts.

Figure 8 shows the organic acid removal from the amino acid free stream by anion exchangers. The adsorbed acids are eluted using ammonium hydroxide solution. The organic acid solution is evaporated and dried to obtain the ammonium salts of the organic acids.

Costs

Capital and operating costs were calculated for each of the alternatives in order to determine which ones should receive further study.

Table I lists the capital costs of the alternatives in order of increasing fixed capital. Concentration of the protein water by evaporation requires the least fixed capital with biological treatment next. Alternatives 2 and 4 are next, both requiring almost the same investment; alternative 4 being higher by about 10 percent. Alternative 5 requires an investment that is outside the range of the other four alternatives at $2,550,000.

Table 1 Fixed Capital Costs

Alt. No.	Alternative	Fixed Capital-$
3	Concentration by Evaporation	514,000
1	Biological Treatment	550,000
2	Protein Recovery + Bio. Treatment (Protein Rec. = $382,000)	807,000
4	Protein Rec. + Conc. by Evaporation	881,000
5	Protein Rec. + Ion Exch. + Bio. (Bio. = $350,000)	2,550,000

Table II shows the operating costs for the alternatives, again in the order of increasing costs. The biological treatment process involves the least operating cost. Among the by-product alternatives, concentration by evaporation incurs the least operating cost. The difference in operating cost between each consecutive alternative, as listed, is considerable, and much greater than the probable error involved in estimating the costs in this category.

Table III shows the uses and estimated probable sales prices for the products obtained from the alternatives. The protein would be used for animal feed or possibly human food. The concentrate from the concentration by evaporation step is mixed with the potato pulp from the starch process in the proportions in which they are produced, and used as cattle or poultry feed. The concentrate without protein, Alternative 4, is also used as a feed additive - the price for this concentrate

Table II Operating Costs

Alt. No.	1 Bio.	3 Conc.	2 Prot. Rec. + Bio.	4 Prot. Rec. + Conc.	5 Prot. Rec. + Ion Exch. + Bio.
Daily					
Deprec.	238*	227**	347	383	1,538
Op. Ex.	367	764	974	1,494	3,500
Total	605	991	1,321	1,877	5,038
Yearly					
Deprec.	35,700**	34,000	52,100	57,500	230,750
Op. Ex.	55,000	114,500	146,000	224,000	525,000
Total	90,700	148,500	198,100	281,500	755,750

*Bio, Amortized at 7 percent for 20 years.

**Depreciation for Alts. 2, 3, 4, 5: Str. Line, Bldgs-20 yrs., Equip.-15 yrs.

Table III Uses and Estimated Prices for Products

Alt. No.	Alternative	Product	Use	Price-¢/lb
1	Bio	None	---	--
2	Protein Recov. + Bio.	Protein	Feed or Food	12.0
3	Conc. by Evap.	Concentrate with Protein	Animal Feed	6.7
4	Protein Recov. + Conc. by Evap.	A. Protein	Feed or Food	12.0
		B. Concentrate without Protein	Feed	5.0
5	Protein Recov. + Ion Exch. + Bio.	A. Protein	Feed	12.0
		B. Amino Acid Mixt.	Feed or Food	15.0
		C. Organic Acid Mixt.	Beverages	31.0
		D. $K_2SO_4-(NH_4)_2SO_4$	Fertilizer	2.2
		E. $(NH_4)_2SO_4$	Fertilizer	2.25

being lower than the concentrate with protein. The amino acid mixture could be used in feed or food. The price for this was estimated from current prices for amino acids. The organic acid mixture would be used in beverages as an acidulant. The price is considered comparable to similar acid mixtures used for this purpose.

The potassium sulfate-ammonium sulfate mixture and the ammonium sulfate salts would be used as fertilizer. The prices were estimated from current prices for these chemicals.

Table IV shows the daily and yearly sales using the prices for the products shown in Table III. The alternatives are listed in order of decreasing sales dollars. The differences in sales between alternatives as listed is probably greater than error in estimating the sales figures. Total operating costs from Table II are subtracted from sales to give the gross income as shown in Table V.

Table IV Sales

Alt. No.	Alternative	Daily-$	Yearly-$
5	Protein Rec. + Ion Exch. + Bio.	2960	444,000
3	Concentration by Evaporation	1244	186,700
4	Protein Recovery + Conc. by Evap.	1100	165,000
2	Protein Recovery + Bio. Treatment	295	44,000
1	Biological Treatment	NONE	NONE

It should be noted that the operating expense figures do not include an allowance for a return on the investment. Therefore, federal income taxes are not inlcuded in the operating expenses. Thus, the net income after taxes for Alternative 3 would be reduced by an amount equal to the federal income tax. Also, the loss shown for the other alternatives would reduce the overall federal income tax of the company by an amount equal to the loss shown times the tax rate.

Table V shows the gross income or loss for each alternative in order of decreasing income (or increasing loss). Alternative 3, Concentration by Evaporation, shows the highest gross income, by far, of all the alternatives listed. Here again, the difference between the figures is greater than error in calculating the figures shown. After the alternative of concentration by evaporation, the biological treatment process has a smaller loss than the remaining by-product recovery processes. From Table V it is apparent that concentration by evaporation offers the only possibility for making an income, assuming the estimated selling prices for the various by-products are reasonably correct.

Table V Gross Income or (Loss)

Alt. No.	Alternative	Daily-$	Yearly-$
3	Concentration by Evaporation	255	38,200
1	Biological Treatment	(605)*	(90,700)
4	Protein Recovery + Conc. by Evap.	(777)	(116,500)
2	Protein Recovery + Bio. Treatment	(1026)	(153,800)
5	Protein Recovery + Ion Exch. + Bio.	(2078)	(311,750)

*Note: Parenthesis indicate loss.

Table VI, which shows selling prices for various levels of profitability, can be used to compare the effects of different prices on the commerical feasibility of the alternative.

Table VI **Selling Prices for Various Levels of Profitability**

Alternative	Product	Product Selling Price, ¢/lb.		
		To Equal Bio. Loss	To Break Even	Est. Market Price
1. Bio	None	--	--	--
2. Protein Rec. + Bio.	Protein	29.1	53.7	12.0
3. Conc. by Evap.	Concentrate with Protein	2.07	5.3	6.7
4. Protein Recov. + Conc. by Evap.	A. Protein	13.9	35.1	12.0
	B. Conc. W/O Protein	5.8	6.3	5.0
5. Protein Recov. + Ion Exch. + Bio.	A. Protein	30.2	37.7	12.0
	B. Amino Acids	37.7	47.1	15.0
	C. Organic Acids	31.0	31.0	31.0
	D. K + NH_4 Salts	2.20	2.20	2.20
	E. $(NH_4)_2SO_4$	2.25	2.25	2.25

For Alternative 2, the Table shows that the protein must be worth almost 54¢ per pound for no loss to occur. This is greater than the estimated selling price of 12¢ per pound. This means that, at current prices for protein, the process is not commerically feasible. In contrast, Alternative 3 has a break-even price lower than the estimated price of 6.7¢ per pound. Of course, any price between 5.3¢, the break-even price, and 6.7¢ will involve no loss or some income will be earned. Thus, there is a likelihood for income for Alternative 3 with current prices for feed. The nutritive value of the feed consisting of pulp mixed with protein concentrate was estimated at 20 percent above that of corn at $47 per ton. On this basis the concentrate alone was estimated to be worth $73.50 per ton at 60 percent solids or 6.7¢ per pound of moisture-free solids. It is possible that a higher price could be obtained if the concentrate were fed to non-ruminant animals since the protein is of excellent quality(2).

Under Alternative 5, only the prices for protein and the amino acid mixture were varied in order to obtain the additional income required for the condition of "break-even" and for the condition of "loss-equal-to-biological-treatment".

Table VI also shows the selling prices of the products for the condition where the gross loss for the alternative would equal the loss for the biological treatment alternative. There is only one alternative shown where the estimated actual market price exceeds both the break-even price and the loss-equivalent-to-biological-treatment price, and that alternative is concentration by evaporation.

CONCLUSIONS

We have seen the results of a preliminary economic evaluation of a number of possible methods of treating the waste effluent from potato starch plants.

Conventional biological treatment of the waste water appears to have both rather high capital cost and rather high operating cost.

Four of the treatment processes yield products, and revenue from the sale of these products would help offset the operating costs. Only one of these processes, however, appears economically feasible at this time; namely, concentration of the effluent by evaporation. Our Laboratory is, therefore, investigating this process on the pilot plant scale. These studies will enable us to project commercial feasibility with greater confidence and also make available samples of the product for testing and evaluation. When further information on this process has been obtained, we will publicize the results.

Development of the protein recovery process on a pilot plant scale was carried out in our Engineering and Development Laboratory by E. O. Strolle. The ion-exchange processes for recovery of inorganics, amino acids, and organic acids were carried through the laboratory scale by E. G. Heisler, James Siciliano and Joseph Schwartz of our Plant Products Laboratory. Much of the basic data needed for process design in our economic analysis were provided by these individuals.

REFERENCES

1. "Recovering Proteins from Potato Starch Factory Effluents - Progress and Prospects", E. O. Strolle, J. Cording, Jr., N. C. Aceto, and E. S. DellaMonica, EMNRD, ARS, talk presented at 20th National Potato Utilization Conference, Riverside, California, July 31, 1970.

2. Unpublished report. J. W. White, Jr., Eastern Marketing and Nutrition Research Division, ARS, U. S. Department of Agriculture, Philadelphia, Pennsylvania 19118.

3. "Recovery of Free Amino Compounds from Potato Starch Processing Water by Use of Ion Exchange", E. G. Heisler, J. Siciliano, R. H. Treadway, C. F. Woodward, American Potato Journal, January 1959, Vol. 36, No. 1, pp. 1-11.

4. "Recovery of Free Amino Compounds from Potato Starch Processing Water by Use of Ion Exchange. II. Large-Scale Laboratory Experimentation", E. G. Heisler, J. Siciliano, R. H. Treadway, and C. F. Woodward, American Potato Journal, February 1962, Vol. 39, No. 2, pp. 78-82.

5. "Potato Starch Factory Waste Effluents. I. Recovery of Potassium and Other Inorganic Cations", E. G. Heisler, S. Krulick, J. Siciliano, W. L. Porter, and J. W. White, Jr., American Potato Journal, Vol. 47, No. 9, September 1970, pp. 326-336.

CONTINUOUS TREATMENT OF CORN AND PEA PROCESSING WASTE WATER WITH *FUNGI IMPERFECTI****

by

Dr. Brooks D. Church*, Harold A. Nash*, Eugene E. Erickson* and
Willard Brosz**

INTRODUCTION

Strains of fungi from the *IMPERFECT* class were examined for their utility in digesting food processing wastes because of their reported ability to grow well on a variety of polysaccharide-containing materials(1) and because of Gray's findings(2) that the mycelium had a high content of good quality protein. It was reasoned that the macroscopic size of the mycelium would simplify its recovery. Further, its high protein content would make it valuable as an animal feed and thus allow recovery of at least part of the cost of the waste treatment.

Laboratory studies reported one year ago(3) showed that these hopes for both efficient BOD removal and high quality protein recovery might indeed be realized. The work was therefore extended from the 5-gallon laboratory stage to two 10,000-gallon pilot plant units at the Green Giant Company plant in Glencoe, Minnesota. The present report treats these pilot-scale studies, which were carried out on corn and pea canning wastes and corn silage waste.

METHODS

The corn and pea waste waters used in these pilot-plant investigations were taken from a receiving lagoon at a point near the plant effluent discharge.

The fungus selected for these studies was *Trichoderma viride* I-23. The fungal choice was based on the previous laboratory screening studies where the criteria used were COD reduction, growth response, mycelial yield, quality of protein and the ability to compete with the natural flora. Two types of aeration systems were used in the pilot plants: a 2-hp floating aerator was installed in a 10,000-gallon

---

*North Star Research and Development Institute, Minneapolis, Minnesota.
**The Green Giant Company, LeSueur, Minnesota.

***This investigation was supported by funds from the Environmental Protection Agency, Water Quality Office, under Grant No. 12060 EDZ and The Green Giant Company, National Canners Association, Wisconsin Canners and Freezers Association, and the Minnesota Canners and Freezers Association.

plastic swimming pool, and a cage rotor was installed in a circular, rubber-lined, 10,000-gallon ditch. In each facility the liquid depth was approximately 3.5 feet. The waste was fed from a constant-head tank; the flow rate, which controlled the detention time, was regulated by varying the size of the discharge orifice in the tank. The effluents from the lagoon and the ditch were discharged through an overflow tube.

A schematic diagram of the pilot-plant flow system is shown in Figure 1; photographs of the facilities are shown in Figures 2 and 3.

A technician was at the pilot installations for eight hours per day to make observations, take influent and effluent samples from both the ditch and the pool, and collect some of the data (*e.g.*, pH, DO, temperature, feed rate, additions of chemicals).

Effluent samples were filtered through pre-weighed Whatman #4 filter paper and the mycelium and filtrates were frozen, along with the unfiltered influent or feed samples, for regular transport to, and analysis in, the laboratory. Every third day samples of unfiltered effluent were taken to the laboratory for phase-microscopic examination of the fungal mycelium.

From our microscopic experience we believe that regular examination of the fungal morphology can serve as an excellent method to indicate waste treatment efficiency. At times of start-up, the inoculum was composed of young, rapidly-growing mycelium containing numerous long growing tips. As the mass of the thallus increased, some granulation and vacuolation occurred in the mycelium. During steady-state digestion of waste nutrients, fungal growth is balanced by loss of mycelium in the effluent. The continuous growth during steady-state digestion is marked by numerous young growing elongated hyphal tips and branches, as shown in Figure 4. A minimal number of lysing hyphae and spores are observed. The actively metabolizing mycelium has very fine homogeneously dispersed cytoplasmic structures. Because the steady-state digestion is near starvation with regard to fungal nutrient, any rapid and radical operational change (*e.g.*,stoppage of feed, pH) will be reflected as early sporulation stages in the thallus as seen in Figure 5. Sporulation develops as hyphal granulation in the first observed change followed, in several hours, by the formation of asexual spores in the hyphae and at the hyphal tips.

If an irregularity in the pilot operation can be detected within eight hours, changes (granulation) can be reversed and spores formed during this time will germinate (Figure 6) to form new mycelium. If the irregularity is longer (*e.g.*, 24 hours), much sporulation will occur and 12 to 18 hours will be required before optimal growth and efficient BOD removal is reestablished.

Inoculation of the pilot plant was accomplished with mycelium grown from an initial potato dextrose agar stock culture of *Trichoderma viride*-I-23. The growth to pilot-plant inoculum scale was carried out in 32-gallon plastic garbage cans. The inoculum was aerated by passing air through plastic pipe inserts with multiple outlet holes.

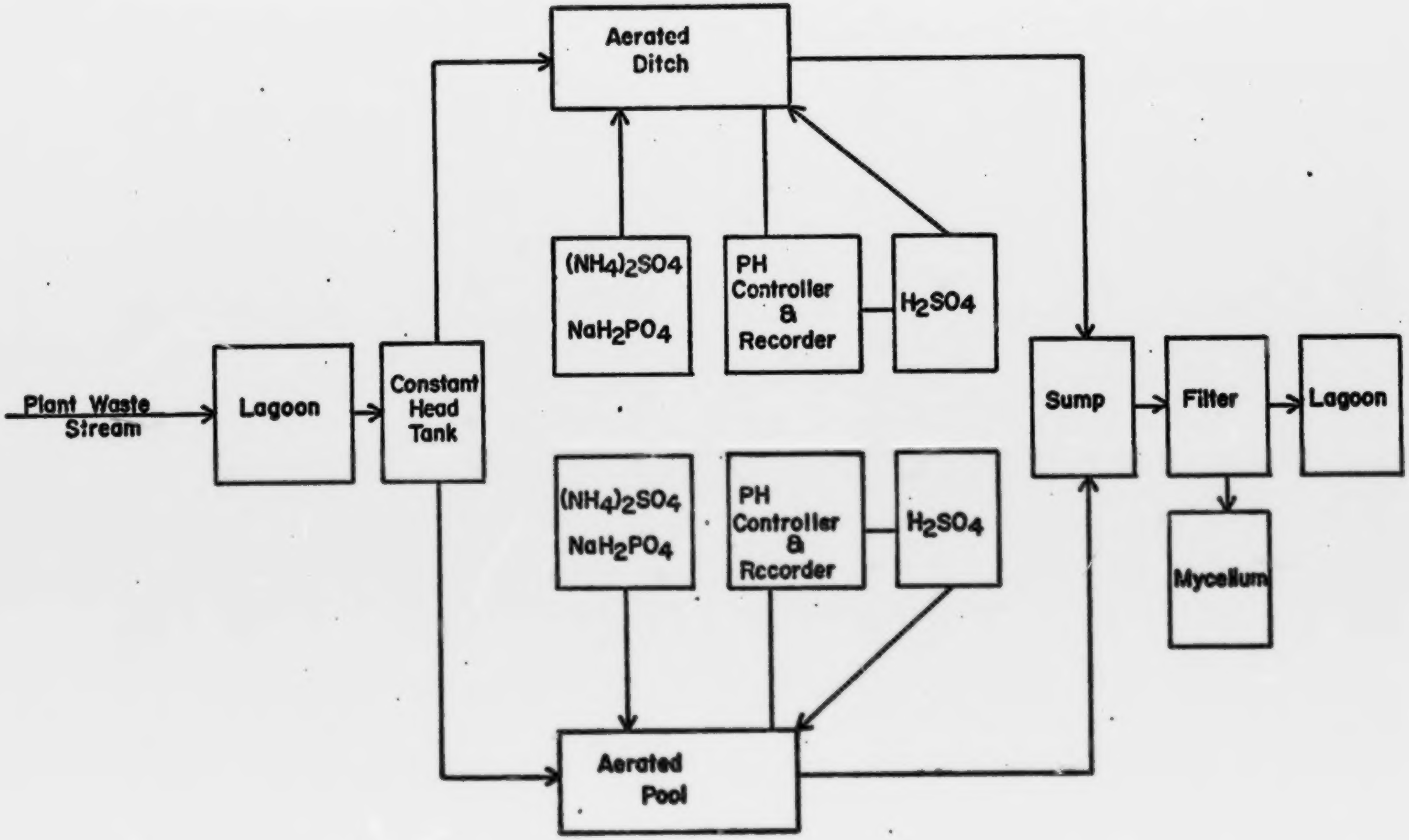


Figure 1. Schematic Diagram of the Pilot-Plant Flow System

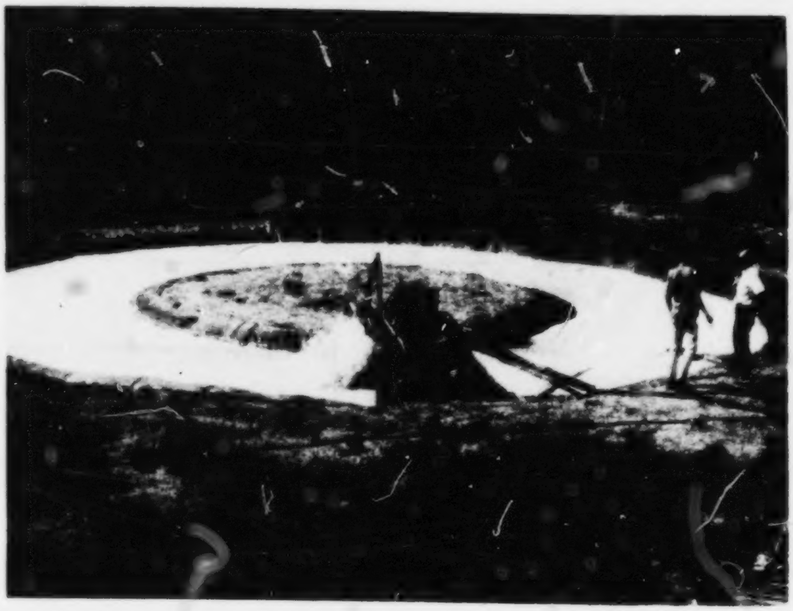


Figure 2. Aerated Ditch Used for Treatment of Corn Canning Waste

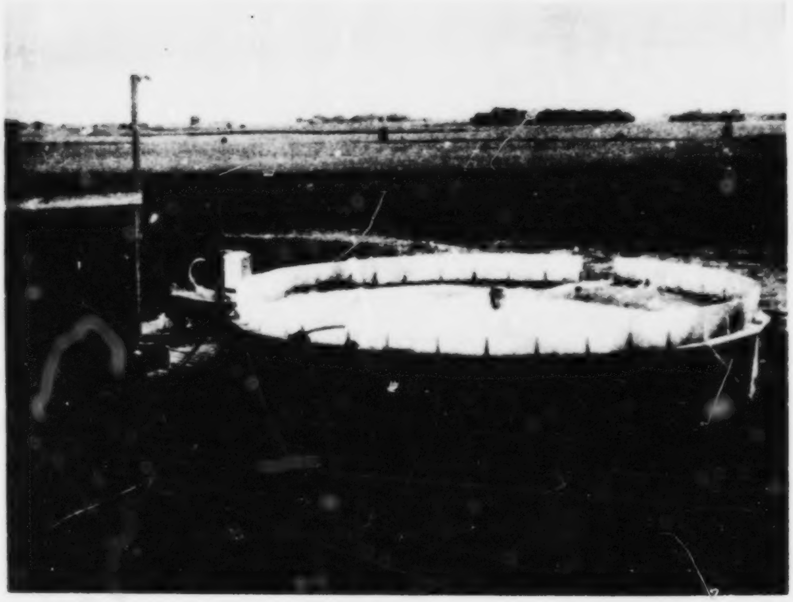


Figure 3. Aerated Pool Used for Treatment of Corn Canning, Pea Canning, and Silage Wastes

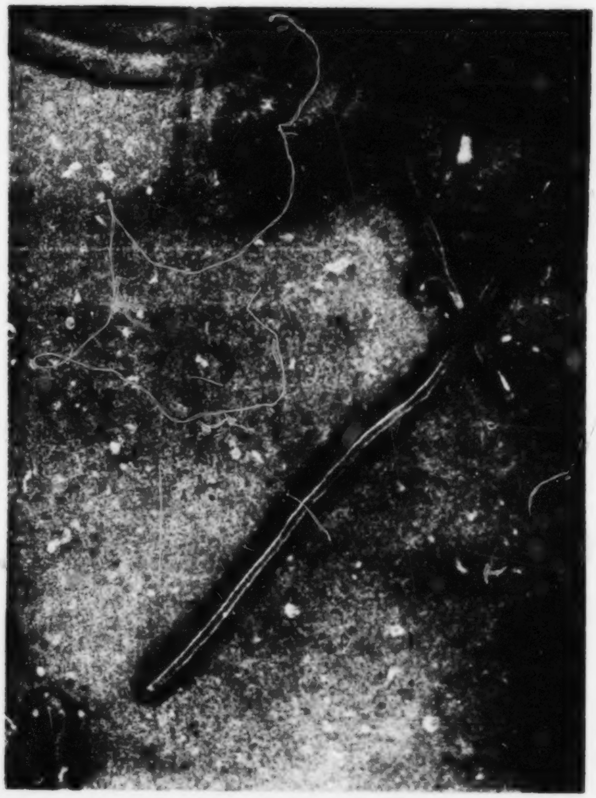


Figure 4. Young Growing *T. viride* Showing Active Metabolizing Hyphal Tips

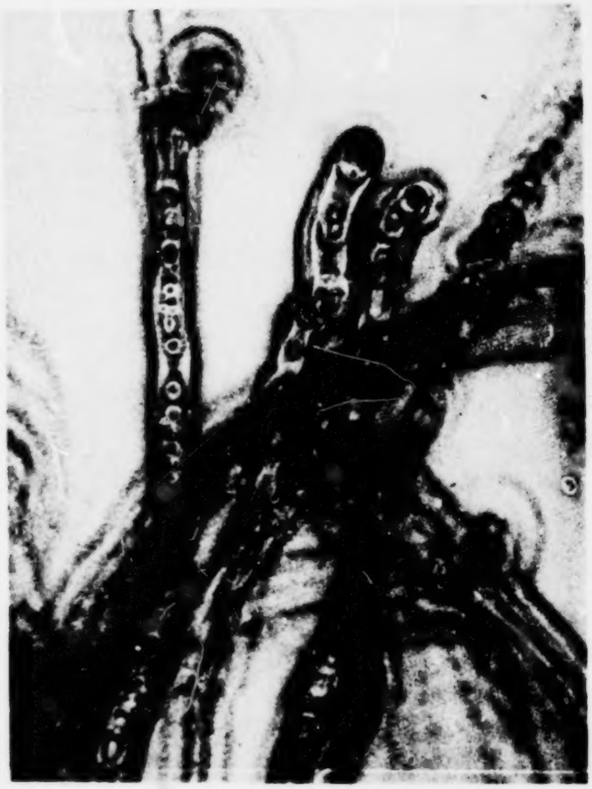


Figure 5. Early Sporulation, Asexual Spores and Cytoplasmic Granulation Can Be Observed

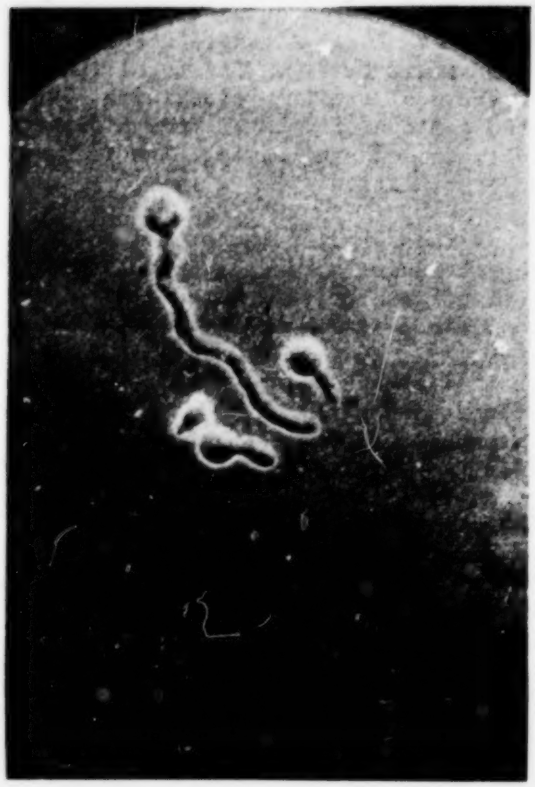


Figure 6. Germination of Spores of *T. viride*
Note new hyphal structures

The growth medium was ground frozen corn or peas, with appropriate amounts of $(NH_4)_2SO_4$ and Na_2HPO_4. Adequate H_2SO_4 was added to adjust and to maintain the pH at 3.2 to 3.7. The total inoculum of 100 gallons was used for the pool or ditch containing 2000 gallons of canning waste and 2500 gallons of water. Thus a 5-percent inoculum was used with regard to the canning waste. New feed was started immediately following inoculation.

The fungal mycelium was recovered from the pool and ditch effluent late in the season by screening through a Sweco Model LC-18-C-333 filter unit. Several mesh sizes were tried and the #120 size appeared most efficient.

Measurements made in monitoring the fermentation included regular determination of influent and effluent COD and BOD_5, and occasional measurement of TOC, temperature, pH, and mycelial mass were determined regularly on the effluent. Microscopic examination of the fungal growth was conducted at least three times a week. Phosphate determinations were made by the Fiske and Subarow method, protein determinations by the Lowry method, carbohydrate by micro-kjeldahl, and ammonium nitrogen measurements by the Conway diffusion technique.(4) Total, dissolved, volatile, and suspended solids were determined according to standard procedures.(5)

RESULTS

1. Pilot-Plant Operation on Corn Waste

Some of the characteristics of the feed are indicated by measurements made on a composite sample comprised of equal aliquots of samples from the heart of the operating season from August 19 to September 20. Results of sample analyses are shown in Table 1.

Table 1. Characteristics of Composite Sample of Corn Waste*

	mg/1
COD	2436
BOD	1564
TOC	1632
Total Solids	2372
Volatile Solids	1390
Ash	1070
Suspended Solids	210
Ammonia Nitrogen	90
Phosphate as P	8.5
Acid to titrate to pH 3.7	450

*At pH 6.9.

Daily records were kept of the principal variables controlled during the 50-day corn canning season. One of these, temperature, remained at approximately 20°C at early afternoon samplings during the bulk of the season. Temperature dipped to below 10°C on the 36th and 37th days of operation and at the end of the season.

The detention time was set to test the effect of variations in waste treatment times, and was occasionally altered in response to other events. It was deliberately long immediately after inoculation. At day 21, the detention time in the ditch was increased for 2 days because a failure of the pH control equipment allowed the pH to drop to levels that impaired culture performance. The pool was operated at longer detention times than desired during part of the season because of partial failure of a feed pump. The detention times together with the COD or BOD levels, governed the feed loading that the system was required to handle each day. Best performance appeared to occur at detention times between 22 and 26 hours.

Ammonium sulfate and sodium dihydrogen phosphate additions were adjusted to provide amounts believed to be required from previous experience. Alterations were made as feed rates were changed, as the average COD changed, and as analyses of the effluent indicated that excesses or supposed deficiencies were encountered. $(NH_4)_2SO_4$ varied between 3.1 and 5.4 lbs per 1000 gallons of feed, and Na_2HPO_4 between 0.1 and 2.3 lbs per 1000 gallons.

The pH control was set at 3.5, and that pH was maintained within ± 0.1 unit, with a few exceptions. A major exception in the case of the ditch occurred on the twenty-first day, when the acid pump failed to turn off and the pH dropped to 1.8. pH control failures also occurred in the pool twice during the first 20 days of operation and destroyed operations during this period. The amount of acid averaged about 4 lbs/1000 gallons of feed. Titrations of the well water used in the canning operations showed an acid requirement of about 2.9 lbs/1000 gallons to bring the pH to 3.5. Titrations of the plant waste directly from the corn canning operations showed a similar requirement. Titrations of plant waste drawn from the receiving lagoon, however, showed a requirement of 6 lbs of acid per 1000 gallons.

The performance of the ditch and pool in removing COD and BOD is shown in Figures 7 through 10. COD removal during favorable periods of operation of the ditch (for example, between days 25 and 36) was about 89 percent. The high effluent COD on day 21 followed failure of pH control with a fall of pH to 1.8. The peak on days 37 and 38 occurred when the temperature dropped to below 10°C. BOD removal was about 97 percent during periods of favorable operation. BOD levels in the effluent vacillated between about 40 and 90, with a mean of about 50, except during upsets caused by extremes of acidity or temperature. It is to be noted that the decreased COD removal related to extreme acidity on day 21 is reflected by a peak in effluent BOD also. The increase in COD levels in the effluent during the

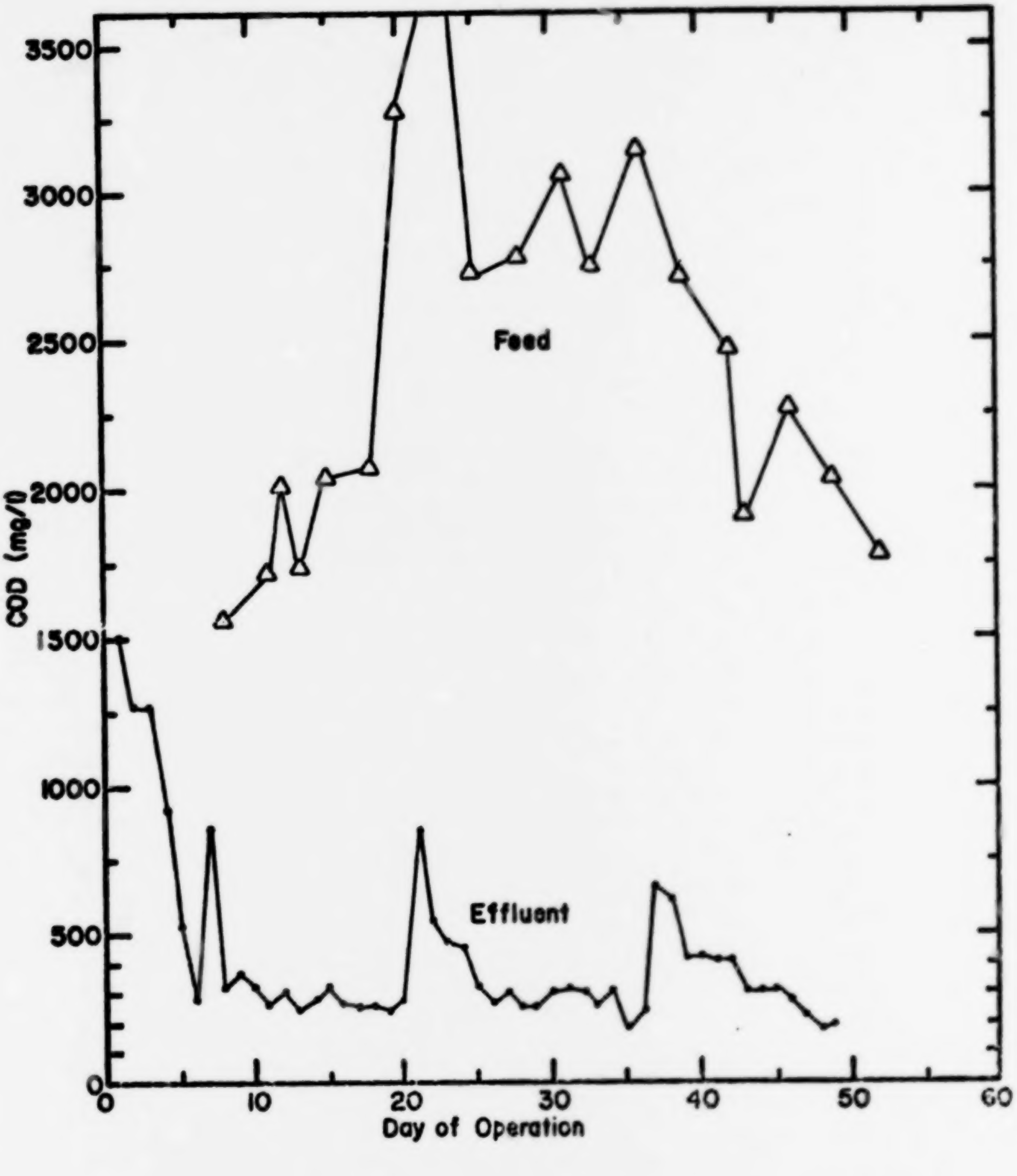


Figure 7. COD of Corn Feed Effluent Streams of the Ditch During Operation on Corn Canning Wastes

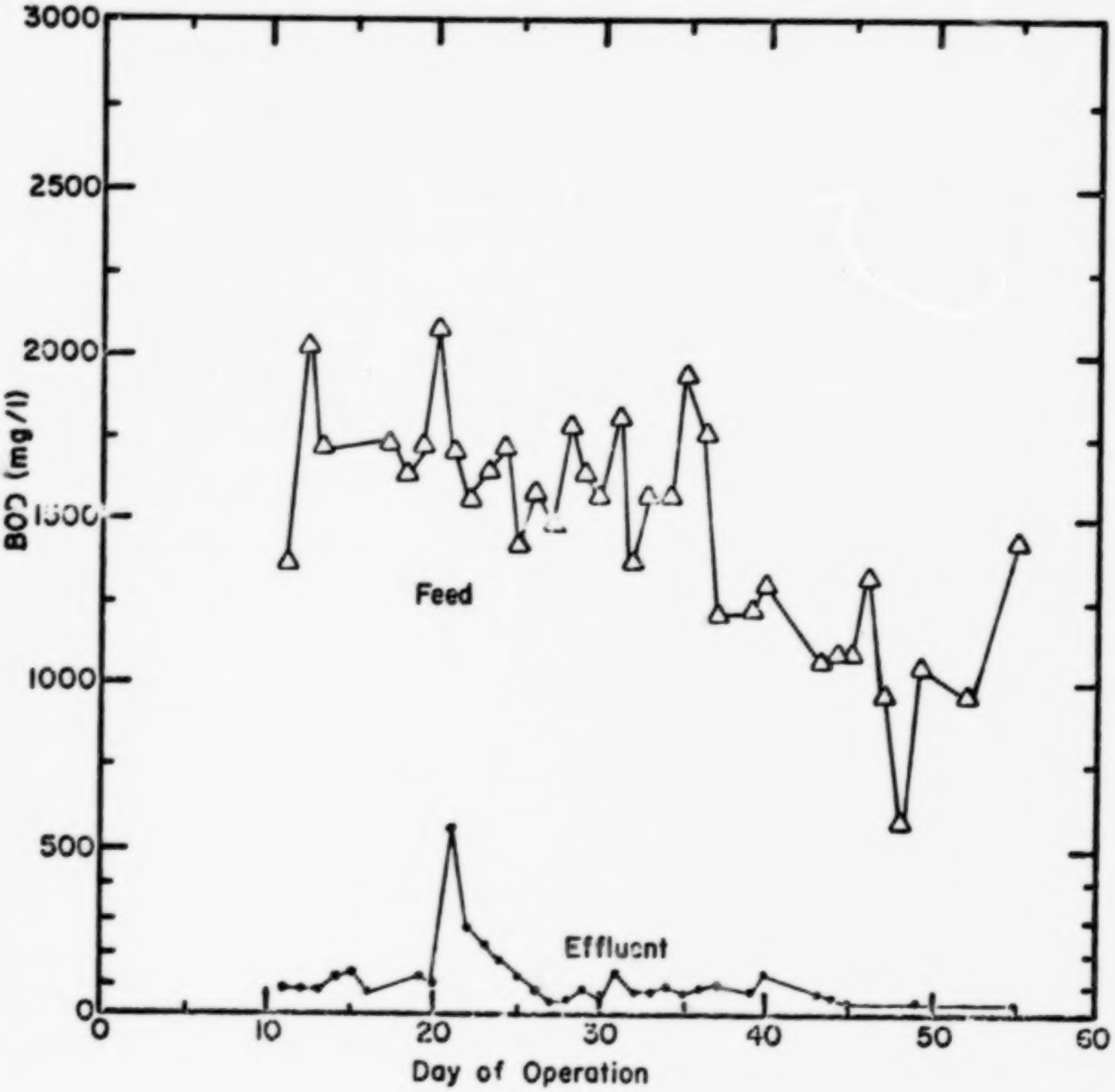


Figure 8. BOD of Feed and Effluent Streams of the Ditch During Operation on Corn Canning Wastes

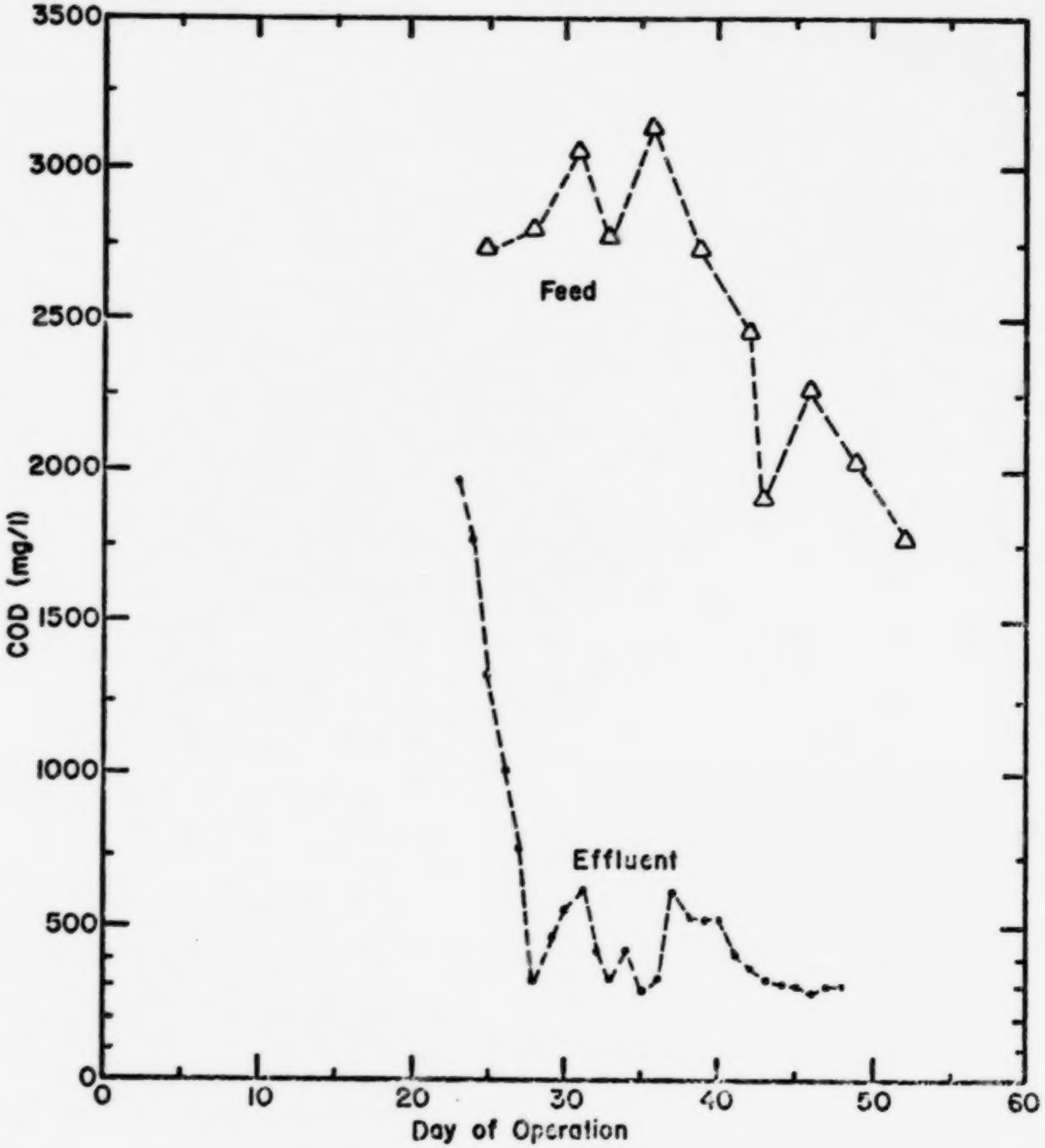


Figure 9. COD of Feed and Effluent Streams of Pool During Operation on Corn Canning Wastes.

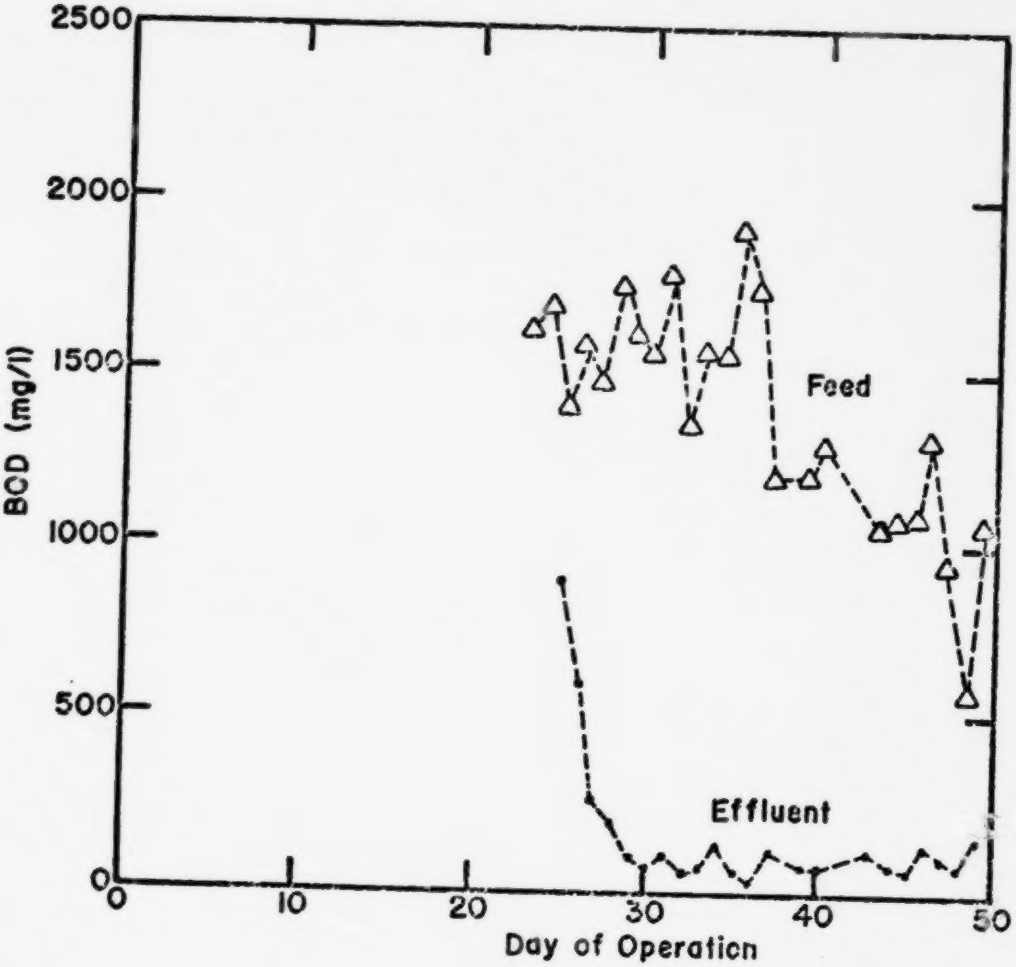


Figure 10. BOD of Feed and Effluent Streams of Pool During Operation on Corn Canning Wastes

period of low temperature on days 37 and 38 is scarcely at all reflected by a corresponding increase in effluent BOD.

The yield of mycelium filtered from daily effluent samples through Whatman No. 4 filter paper varied from about 0.55 gram to 0.8 g/l. Values are shown graphically in Figure 11. The dry weight of recovered mycelium averages 50 percent of the weight of BOD removed for both the ditch and the pool. The amount of mycelium recovered was relatively constant. The spikes from days 6 to 9 for the ditch are thought to be the result of imperfect sampling procedures.

The microbial pattern in the aerated ditch remained predominately *Fungi Imperfecti*, but not at all time *T. viride*. Yeasts and bacteria were always present, but they formed less than 0.1 percent of the total biomass. A fungus, indentified as a *Geotricum*, appeared in the ditch a few days after inoculation with *T. viride*. By mid-season, *Geotricum* comprised 50 to 70 percent of the mycelial mass. This fungus became less prominent later in the season, and in the terminal stage of the operation it comprised approximately 20 percent of the mycelial mass. An occasional clump of *Geotricum* was observed in the pool, but it never became prominent. *Geotricum* had been observed to occur as a minor component in the continuous culture laboratory studies on corn waste conducted prior to these pilot studies.

Several techniques were investigated for recovery of effluent mycelium. The mycelium was too fine for efficient recovery by simple screening as had been successful in laboratory studies. We believe this was due in part to the *Geotricum* fungal strain which produces very small clumps, in part to the colder temperatures experienced in the pilot plants, and in part to the higher shearing forces introduced by the aerators.

The use of a Sweco vibratory filter was explored to a considerable extent. Results are shown in Table 2. These results are considered the poorest that might be expected, since they were obtained late in the season when the mycelium was especially fine. The mycelium concentrate from the No. 120 Sweco screen contained 2.5 percent solids. It was filtered readily on a vacuum filter to produce a cake 0.5- to 1-inch thick, containing 20 percent solids.

Table 2. Performance of Sweco Vibratory Filter on Corn Waste Effluents

Screen Mesh	Gallons Flow per sq ft per min	Percentage Mycelium Recovery	COD Effluent	BOD Effluent
94	8		1352	
105	6		928	
120	6	52	664	142
165	2	65	332	74

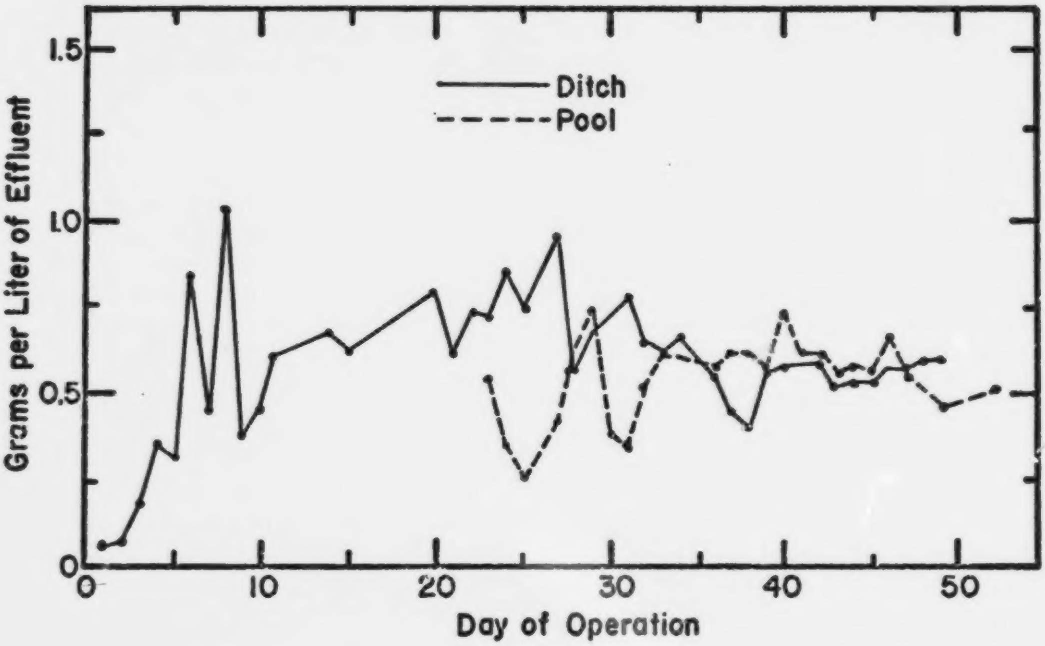


Figure 11. Dry Weight of Solids Recovered from Effluent Streams by Filtration During Operation on Corn Canning Wastes

The vacuum filter cake formed from fungal material collected on the Sweco unit could itself be used as a filter media to clean up the effluent from the Sweco. A 0.5-inch fungal cake accommodated 20 gallons of Sweco effluent through a 10-inch diameter filter at about 24 inches of Hg pressure drop, before slowing to a filtration rate of 0.2 gpm/sq ft.

The dissolved oxygen levels in the ditch never dropped below 3.7 mg/l; the 5 hp rotor was overpowering. DO levels in the pool, however, approached zero on several occasions, thus providing a basis for estimating aeration requirements. If one assumes the floating aerator in the pool delivered 2 lb DO per hp-hr, 96 lb would be delivered/day. One three-day period (days 35-38), the unit was handling 120 lb of BOD/day at DO levels less than 1 mg/l. From the above values, an oxygen consumption of 0.8 lb per lb of BOD is obtained.

Another approach, which we carried out a number of times, was to measure the rate of change in DO levels in samples removed from the ditch. We assumed that oxygen consumption of the ditch sample continued in a closed system that was fed waste nutrient at the same rate of feeding as in the ditch. Assuming BOD was being removed at the same rate in the sample as in the ditch, the calculated rate was 0.7 lb of O_2 per lb of BOD removed.

The overall effectiveness of the fungal digestion on corn waste is shown in Table 3. The data used in preparing this table was taken from a 20-day period of stablized favorable performance.

Table 3. Characteristics of Composite Samples of Corn Waste Feed and Effluent Collected in Mid-Season

(Composites are from the same 20 days in each instance)

	Milligrams per Liter		
	Feed	**Effluent**	**Clarified Effluent**
COD	2436	305	215
BOD	1580	59	41
TOC	1608	104	81
Total solids	2372	1743	1536
Volatile solids	1490	521	432
Ash	1070	984	998
Suspended solids	210	101*	0
Mycelium	0	646	0
Ammonia N	90	23	0.2
$PO_4^{\equiv}$	9	1	0.01

*"Suspended solids" in this instance refers to materials not removed by filtration but which could be collected by centrifugation at 5000 rpm.

2. Pilot-Plant Operation on Pea Canning Waste

The aerated pool was operated on pea canning wastes for 35 days. Temperatures were generally above 18°C. Detention times were initially 45 hours and were stepped down to 18 hours by the end of the season. Additions of $(NH_4)_2SO_4$ and Na_2HPO_4 in lbs per 1000 gallons of feed were 1.8 to 4.4 and 0 to 0.7, respectively. An average of 6.5 lb of H_2SO_4 per 1000 gallons of feed was required to maintain a pH of 3.5 Performance is summarized in Table 4. These values represent analyses over 20 days of the operating season. During the last 15 days of the season the effluent BOD was consistently below 45.

Table 4. Analysis of Feed and Effluent Pea Wastes

	Milligrams per liter	
Test	Feed	Effluent
COD	1650	324
BOD_5	772	61
TOC	962	126
Total Solids	6815	6585
Volatile Solids	917	711
Ash	5898	5874
Suspended Solids	264	0.8
Mycelium	0	420
Phosphate as P	13	10

The microbial pattern of the pea waste was one of definite predominance of *Fungi Imperfecti*, with bacteria, yeast, and protozoa being present in small numbers. On about the eleventh day, there was a shift in fungal type from *T. viride*, which had been used as an inoculum, to a *Fusarium*. The amount of *T. viride* decreased until, at the end of the season, it formed not more than ten percent of the mycelial mass. The *Fusarium* formed a fine floc which could be recovered on filter paper but not on coarse filters.

Laboratory experiments showed that the changes which took place in the receiving lagoon favored *Fusarium* and discouraged *T. viride* growth.

3. Pilot-Plant Operation with Silage Waste

In the corn processing operation, the husks and cobs accumulate in a large pile that undergoes anaerobic fermentation. Juices are expressed that have BOD levels as high as 38,000 mg/l. During the last 12 days

2. Pilot-Plant Operation on Pea Canning Waste

The aerated pool was operated on pea canning wastes for 35 days. Temperatures were generally above 18°C. Detention times were initially 45 hours and were stepped down to 18 hours by the end of the season. Additions of $(NH_4)_2SO_4$ and Na_2HPO_4 in lbs per 1000 gallons of feed were 1.8 to 4.4 and 0 to 0.7, respectively. An average of 6.5 lb of H_2SO_4 per 1000 gallons of feed was required to maintain a pH of 3.5 Performance is summarized in Table 4. These values represent analyses over 20 days of the operating season. During the last 15 days of the season the effluent BOD was consistently below 45.

Table 4. Analysis of Feed and Effluent
Pea Wastes

	Milligrams per liter	
Test	Feed	Effluent
COD	1650	324
BOD_5	772	61
TOC	962	126
Total Solids	6815	6585
Volatile Solids	917	711
Ash	5898	5874
Suspended Solids	264	0.8
Mycelium	0	420
Phosphate as P	13	10

The microbial pattern of the pea waste was one of definite predominance of *Fungi Imperfecti*, with bacteria, yeast, and protozoa being present in small numbers. On about the eleventh day, there was a shift in fungal type from *T. viride*, which had been used as an inoculum, to a *Fusarium*. The amount of *T. viride* decreased until, at the end of the season, it formed not more than ten percent of the mycelial mass. The *Fusarium* formed a fine floc which could be recovered on filter paper but not on coarse filters.

Laboratory experiments showed that the changes which took place in the receiving lagoon favored *Fusarium* and discouraged *T. viride* growth.

3. Pilot-Plant Operation with Silage Waste

In the corn processing operation, the husks and cobs accumulate in a large pile that undergoes anaerobic fermentation. Juices are expressed that have BOD levels as high as 38,000 mg/l. During the last 12 days of the pea canning season, silage juice from the previous year's corn processing was mixed with the pea waste so that the silage juice contributed about two-thirds of the incoming BOD. BOD levels of the feed were adjusted to 1500 mg/1. Detention time was 18 hours, temperature was above 20°C, the sulfuric acid requirement was 8.1 lbs per 1000 gallons of waste, and phosphate and ammonia additions were not required. COD removal was about 83 percent, and BOD about 95 percent during the first five days after silage addition. This later decreased to 80 percent. The decrease in performance was associated with a drop in DO levels to near zero. Oxygen use was calculated to be about 0.5 lb per lb BOD removed. The biomass continued to be dominated by the *Fusarium* which had become the dominant fungus in the pea waste fermentation.

DISCUSSION

The general effectiveness of the *Fungi Imperfecti* digestions on the three wastes to which it was applied in the pilot-plant studies is summarized in Table 5. The figures used in preparing the table are neither the best nor worst that could have been chosen from performance data, nor are they general averages; rather they represent averages from periods of stabilized favorable performance. BOD removal was good and COD removal was fair in the cases of both corn canning wastes and pea canning wastes. In neither instance was removal as good as obtained in laboratory fermentations where BOD removal ran above 99 percent and COD removal above 96. The reason for the poorer performance is thought to lie partly in the finer mycelium produced in the pilot-plant operations. Samples for analysis were prepared by filtration of a relatively small volume of effluent through Whatman No. 4 filter paper. Because the mycelium was fine, this procedure did not produce an entirely clear effluent. In the laboratory a much larger mycelium was produced which was retained on the filter with more facility.

Table 5. General Efficiency of *Fungi Imperfecti* Process

	Corn Canning Wastes	Pea Canning Wastes	Silage Wastes
Percent BOD removal	96	95	80
Percent COD removal	88	81	83
Percent TOC removal	93	87	85
Mycelium produced per unit BOD removed	0.5	0.6	0.3
H_2SO_4 use -- lb/1000 gallons	4.0	6.5	8.1
Retention time -- hours	22	18	18

Nitrogen and phosphate removal is of particular interest in that it is desirable that levels in the effluent be very low to minimize contributions to entrophication. In the 1970 season of operation, we inadvertently added more ammonium sulfate and sodium phosphate than required either by calculation or by previous experience. Even so, the levels of phosphate were uniformly lower in the effluent than in the influent, and at several periods were essentially zero. Nitrogen levels were likewise essentially zero at some periods of operation. These low levels had no apparent effect on BOD or COD removal. These observations, coupled with observations in the laboratory, make it appear highly likely that the process can be operated with almost no leakage of inorganic nitrogen or phosphorus into the effluent stream.

Acid usage was higher than expected on the basis of laboratory experience. This may only reflect a higher level of water hardness and a lower BOD concentration. Another factor was the anaerobic changes that took place in the lagoon from which the wastes were drawn. Direct titration of fresh wastes and of lagoon wastes showed that almost twice as much acid was required to titrate the material drawn from the lagoon as was required to titrate the fresh plant wastes. The acid actually required in the treatment was about two-thirds that required to titrate lagoon wastes; thus giving evidence of some acid production by the digestion itself. It is quite evident that a variety of changes occur quite quickly in the lagoon. These are evidenced both by the effect of the lagoon materials on *T. viride* growth and by changes in odor and color. The amount of base required to return the effluent to neutrality was found to be only five percent as much on an equivalency basis as required of acid to affect the acidification.

Low temperatures definitely limited the effectiveness of the process. During the first season, temperatures below 12°C had a considerably adverse effect. During the 1970 season, temperatures down to 10°C were successfully accommodated. Successful operation at still lower temperatures could probably be achieved if part of the effluent mycelium was recycled. It is also possible that on prolonged operation at low temperatures, selection would take place for substrains that grow rapidly at low temperatures.

ECONOMIC ESTIMATES

Economic estimates in terms of costs per pound of BOD removed are given in Table 6. Among the factors that would lower operating costs per pound of BOD to a significant degree are higher BOD concentrations, longer operating seasons, softer water, wastes containing adequate nitrogen and phosphate, and a mycelium that filters as readily as did laboratory materials.

Table 6. Cost Estimates on Corn Processing

	Cents per Pound BOD
H_2SO_4	0.43
$(NH_4)_2SO_4$	0.42
NaH_2PO_4	0.10
Aeration	
Power	0.39
Investment	1.16
Labor	0.83
Filtration	
Sweco	0.09
Sand bed	0.46
Vacuum Filter	0.33
Drying	
Heat	0.20
Investment	0.46
Total	4.87
Credit for dry solids	-1.75
Net Cost	3.12

In making the estimates, it has been assumed that the BOD concentration in 1,000,000 gallons per day of feed is 1600 mg/l. Sulfuric acid cost was estimated at 1.7 ¢/lb and it was assumed that 3 lbs would be required per 1000 gallons of feed. Ammonium sulfate at 2 ¢/lb has been assumed for a requirement of 2.5 lbs/1000 gallons of feed. This is less than the 3.5 lbs used during the bulk of the operation in 1970, but is adequate to give a mycelium with a protein content of 50 percent and is in line with previous experience on requirements.

In calculating aeration costs, it has been assumed that 0.7 lb of dissolved oxygen will be required for each pound of BOD removed, that 1 hp delivers 2 lb of dissolved oxygen, and that electricity will be available at 1.5 ¢/kilowatt-hour. In calculating investment costs, it has been assumed that $500/hp will pay for both aeration equipment and auxilliary equipment, including the lagoon; that interest costs will be 7 percent; that the investment would be amortized over 10 years; and that the unit will be operable for 90 days out of the year. In calculating labor costs, it has been assumed that one man can take care of the unit and that $100 a day will be adequate to cover this item.

For filtration, it has been assumed that a combination of a Sweco unit, a sand bed, and vacuum filter would be required. For the Sweco unit, it has been assumed that a 40-sq ft unit would be required. Such a unit would cost about $7000. A sand bed to handle one million gallons a day has been assumed to cost $35,000. A vacuum filter to dewater 6000 lb of solids/day has been assumed to cost $25,000. A drum drier to handle 6000 lb/day will probably cost about $35,000, and the power cost for drying from 80 percent down to 10 percent moisture has been estimated at 0.39 ¢/lb of dry product. Sale of the product might be expected to return 3.5 ¢/lb by analogy with the selling price of soy meal comparable in protein content and quality.

Operating on a year-around basis would reduce investment costs to one-fourth those listed, reducing the total cost, before credit is taken for the product, to about 3.0 ¢/lb of BOD. Production of a readily filterable material, as was accomplished in the laboratory, would eliminate the need for the sand filter and give a cost (on a year-around basis) of about 2.8 ¢/lb of BOD. The credit of 3.5 ¢/lb of product, or 1.75 cents on a pound of BOD basis, would reduce the net cost to 1.12 ¢/lb of BOD treated. Further economies would be possible if oxygen requirements, or costs, and chemical use, could be lowered.

For filtration, it has been assumed that a combination of a Sweco unit, a sand bed, and vacuum filter would be required. For the Sweco unit, it has been assumed that a 40-sq ft unit would be required. Such a unit would cost about $7000. A sand bed to handle one million gallons a day has been assumed to cost $35,000. A vacuum filter to dewater 6000 lb of solids/day has been assumed to cost $25,000. A drum drier to handle 6000 lb/day will probably cost about $35,000, and the power cost for drying from 80 percent down to 10 percent moisture has been estimated at 0.39 ¢/lb of dry product. Sale of the product might be expected to return 3.5 ¢/lb by analogy with the selling price of soy meal comparable in protein content and quality.

Operating on a year-around basis would reduce investment costs to one-fourth those listed, reducing the total cost, before credit is taken for the product, to about 3.0 ¢/lb of BOD. Production of a readily filterable material, as was accomplished in the laboratory, would eliminate the need for the sand filter and give a cost (on a year-around basis) of about 2.8 ¢/lb of BOD. The credit of 3.5 ¢/lb of product, or 1.75 cents on a pound of BOD basis, would reduce the net cost to 1.12 ¢/lb of BOD treated. Further economies would be possible if oxygen requirements, or costs, and chemical use, could be lowered.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to several persons who have taken a most helpful interest in the study.

Mr. Dale Bergstedt for his efforts in securing many items of equipment and for coordinating the efforts of the Green Giant Company, North Star, and commercial people who loaned or rented some of the material.

Mr. Clarence Sprague of the Green Giant Company was most appreciated for his many helpful suggestions and ideas in the construction and maintenance of the pilot-plant facilities.

We especially wish to acknowledge the cooperation, timely help, and friendliness expressed by all members of the Agricultural Production Department of the Green Giant Company, Glencoe, Minnesota.

Finally, a special expression of appreciation to Mr. Donald Hartung for his continued, responsible vigilance of the pilot-plant facilities throughout the study.

REFERENCES

1. Mandels, M., and Reese, E. T., "Fungal Cellulases and the Microbial Decomposition of Cellulosic Fabric", *Develop. in Indust. Microbiol.*, 5, 5 (1964).

2. Gray, W. D., *The Use of Fungi as Food and in Food Processing*, T. S. Furia, Ed., CRC Press, Cleveland, Ohio (1970).

3. Church, B. D., and Nash, H. A., *Use of* Fungi Imperfecti *in Waste Control*, Water Pollution Control Research Series 12060 EHT 07/70, U. S. Department of the Interior, Federal Water Quality Administration (1970).

4. Conway, E. D., *Microdiffusion Analysis and volumetric Error*, McMillan, New York, 5th Edition, p 98 (1962).

5. *Standard Methods for the examination of water and wastewater*, American Public Health Association, New York, 12th Edition, p 422 (1965).

CANNERY WASTE TREATMENT WITH RBC AND EXTENDED AERATION PILOT PLANTS

by

R. J. Burm, M. W. Cochrane, and K. A. Dostal*

INTRODUCTION

In addition to the monitoring of various research grants throughout the country, the Food Waste Research Section of the Pacific Northwest Water Laboratory conducts "inhouse" research ranging from small bench-top studies to the operation and investigation of full-size food waste treatment facilities.

This paper summarizes the observations made during the operation of two waste treatment pilot plants at the United Flav-R-Pac cannery in Salem, Oregon during the 1969 and 1970 canning seasons.

Operation of the two plants during 1970 was somewhat unique because they were run as part of a graduate fellowship program between Oregon State University and the Pacific Northwest Water Laboratory. Under the program the laboratory employs a university graduate student while the student fulfills his M.S. Thesis requirement by conducting research in an area of mutual interest to both institutions. A much more complete description of the operation and daily evaluation of the pilot plants will therefore be forthcoming when the graduate student completes his research report and submits it to the University in May or June, 1971.

The main objective of the research was to evaluate the applicability of two waste treatment principles as a means of pre-treating cannery waste prior to discharge to a municipal system or as the only treatment for the waste before discharge to a receiving water.

DESCRIPTION OF PILOT PLANTS

Both pilot plants used aerobic treatment with one using a form of extended aeration and the other a relatively new principle in this country referred

---

*R. J. Burm and K. A. Dostal are, respectively, Sanitary Engineer and Chief, Food Waste Research Branch, National Waste Treatment Research Program, Pacific Northwest Water Laboratory, Environmental Protection Agency, 200 S.W. 35th Street, Corvallis, Oregon; M. W. Cochrane is a Graduate Associate, Oregon State University, Sanitary Engineering Department.

Preceding page blank

to as a Rotating Biological Contactor (RBC).** Details of each plant are presented below.

Aeration Tank

The extended aeration pilot plant consisted of a 25-foot diameter aluminum tank with a water depth of 9 feet and a capacity of 32,500 gallons. Oxygen was provided with a 1-horsepower floating Welles aerator. Effluent from the tank passed through a 2.5 x 5-foot tube settler. Tube depth was 2 feet and the tubes were sloped 60° from the horizontal plane. The aerator had a theoretical (and demonstrated) capacity to prevent any settlement of volatile suspended solids in the bottom of the tank. The tank therefore could be considered a combination of extended aeration and sludge digestion or long-term activated sludge with 100 percent sludge recycle. Theoretically, the unit should have the capacity of removing significant amounts of BOD while the tube settler prevents excessive volatile suspended solids from being discharged in the effluent. Cell matter synthesized from the BOD would be reflected in a buildup of the mixed liquor suspended solids concentrations. In the ideal situation, the unit would remove the BOD from the cannery wastes throughout the canning season while accumulating the synthesized cell material, and then endogenously destroy the cell matter after the close of the season. A picture of the aeration tank and the top of the tube settler compartment is shown in Figure 1.

RBC

Rotating biological contactors consist of one or more stages of discs mounted on rotating shafts. The shafts are positioned in such a manner that the disc surface area dips into and out of the liquid waste during rotation. Biological masses attach themselves and grow on the discs and these masses are aerated by exposure of the discs to the atmosphere during rotation. Some aeration is also provided to the waste water by the actual physical rotation of the discs.

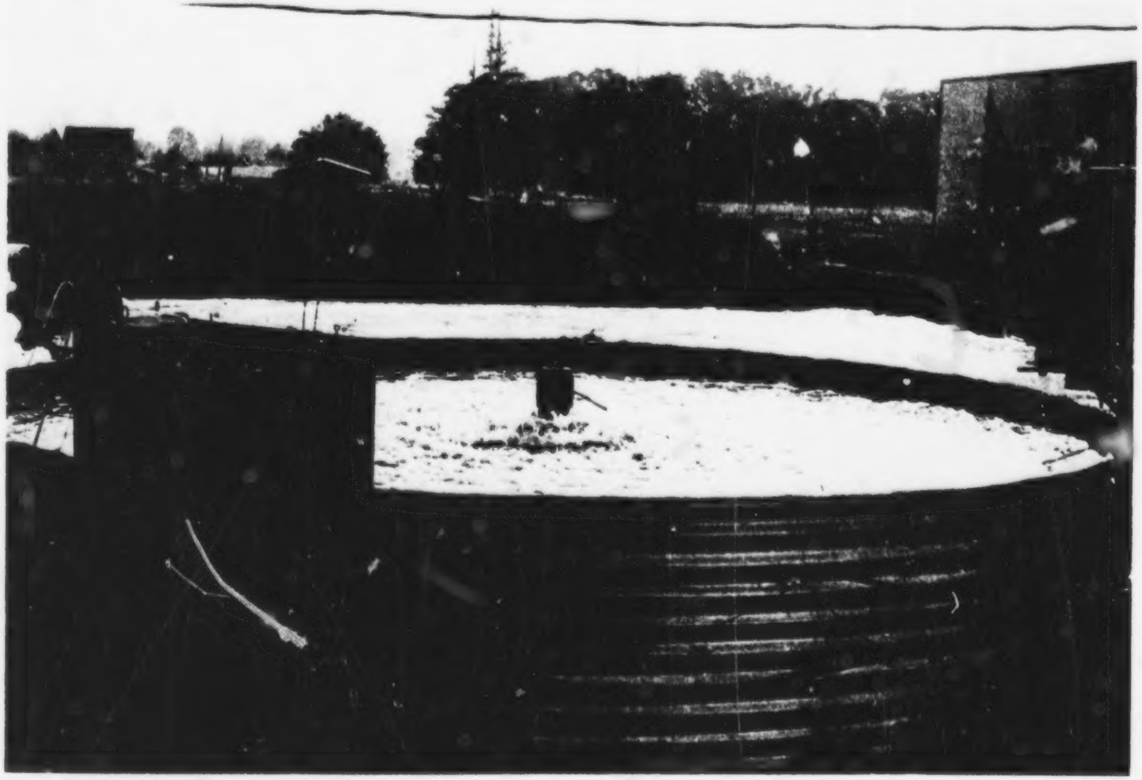
During the 1969 canning season attempts were made to operate a small RBC unit which had been originally used in an earlier research grant involving domestic sewage. This unit consisted of ten separate sets of discs with individual shafts and hydraulic drive motors. Operating and maintenance problems were numerous and no useful data were obtained in 1969.

The unit used during the 1970 canning season was a larger and more refined model owned by the Autotrol Corporation. The entire package unit consisted of a feed scoop chamber, two disc chambers, and a final clarifer with a sludge scoop. The feed scoop and both sets of discs were on a central

---

**Mention of trade names or commercial products does not constitute endorsement or recommendation for use by EPA.

Figure 1



Aeration Tank Installation - United Flav-R-Pac Cannery, Salem, Oregon chain driven shaft attached to a half-horsepower motor. This drive system proved to be far superior to the small RBC unit and few operational problems were encountered. Specific dimensions and operating data are as follows:

Disc diameter : 1.75 meters

No. of discs per chamber : 45 and 46

Disc speed : 4 rpm

Disc thickness : 7/16 inch

Disc spacing : 1/2 inch

Clarifier surface loading : 190 gpd/ft^2 @ 2 gpm

A picture of a similar unit is shown in Figure 2.

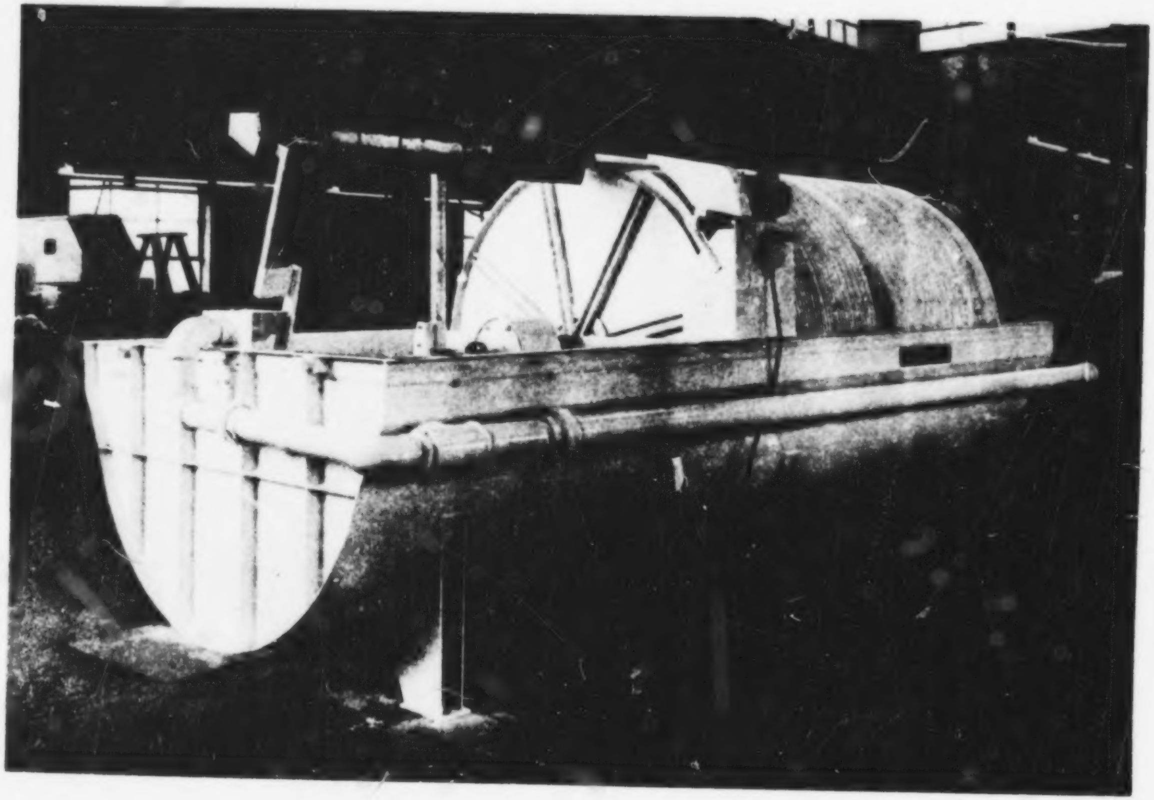
WASTE CHARACTERIZATION

Processing at the Flav-R-Pac Cannery begins in May or June with strawberries and ends in November or December with carrots and/or squash. Other fruits and vegetables processed are cherries, prunes, beets, beans, corn, and a limited amount of potatoes. The cannery operates intermittently for the first few weeks but operation expands to seven days a week - 24 hours a day during the peak of the season. A summary of the observed wastewater characteristics during the August-November period is presented in Table 1.

Table 1 provides an indication of the overall pattern of the waste characteristics at the cannery during various times of the year. Variations depend on such factors as condition of the crops, different combinations of crops, and changes in water usages in the cannery. The table shows a buildup in the COD of the waste during August with maximum values reached in September when various combinations of corn, beets, beans, squash and prunes are being processed. COD levels generally begin to fall through October and November as the quantity and type of vegetables diminishes.

Most organic data will be presented in this paper in the form of COD rather than BOD. This is done because more COD data were generated and also because the BOD test is not considered as reliable or reproducible. COD/BOD ratios are shown in Table 1 and it is interesting to note that the ratio increases later in the season simultaneously with the introduction of squash into the cannery processes.

Figure 2



Rotating Biological Contactor

Table 1. Flav-R-Pac Cannery--Salem, Oregon. Average Process Waste Water Values, 1969-1970 Seasons*

Period	Vegetables Processed	COD Mg/l	VSS Mg/l	pH**	Flow Mgd	COD/ BOD
8/1-8/15	Bn, Bt	750	80	6.8	.76	--
8/16-8/31	Bn, Bt, C	1260	170	5.7	.81	1.25
9/1-9/15	Bn, Bt, C	1800	455	5.9	.81	1.15
9/16-9/30	Bt, C, P, S	1430	245	6.4	.68	1.50
10/1-10/15	Bt, C, Ca, S	1330	275	6.1	.77	1.40
10/16-10/31	Bt, Ca, S	1200	360	6.0	.78	1.60
11/1-11/15	Ca, S	575	155	5.8	.93	1.45

Bn - Beans
Bt - Beets
C - Corn
Ca - Carrots
P - Prunes
S - Squash

*Does not include silt wash water.

**pH - median values.

Volatile suspended matter did not fall off in October and this is attributed to the processing of squash as well as organic content in the soil particles adhering to the carrots.

Total nitrogen and phosphorus values during the processing season were relatively low when compared to carbonaceous material. The raw waste mean influent value for total nitrogen was 25.6 mg/l and for total phosphorus (as P) was 4.1 mg/l during the 1970 season. Values were, in fact, deficient to the point that supplementary nitrogen and phosphorus had to be added to the pilot plants. Standard deviations were 11.0 and 3.9, respectively.

AERATION TANK OPERATION

1969

The aeration tank was assembled at the Flav-R-Pac location during August, 1969, and was placed into operation at the end of August. The system never worked satisfactorily during the 1969 season because the sludge rarely showed any tendency to settle under quiescent conditions. As a result, the tube settler was ineffective and the mixed liquor volatile suspended solids concentrations averaged only 320 mg/l over the entire season. The poor performance is attributable to the following:

1. The unit was started near the peak of the canning season and food to microorganism ratios were in excess of 1.0 for the initial period of operation.

2. A period of nutrient starvation occurred in early October when the nutrient feed system broke down.

3. Large quantities of silt were routed past the aeration tank intake by the cannery during the latter part of October. This was done because the canner's silt pond became full and the silt had to be routed in the new direction. The silt either entered the aeration tank or repeatedly damaged or clogged the intake pumps and thereby stopped the feed to the tank.

1970

Operation during 1970 was much more successful because of the following:

1. Process modifications at the cannery kept the silt water away from the intake.

2. A more gradual start-up earlier in the canning season.

3. Much more diligent operation and maintenance of the equipment.

Nutrients were added during both seasons in the form of dissolved commercial urea and "9-30-0" liquid phosphorus fertilizer. Close attention was not paid to the nutrient feed rates except to assure that at least enough was being added to maintain a BOD:N ratio equal to or in excess of 20:1 and a BOD:P ratio equal to or in excess of 100:1.

A continuous loading limitation during most of the 1970 season was the inability of the 1-horsepower aerator to provide sufficient oxygen to the system. DO levels dropped to 0.2 mg/1 on September 1 and, for the next two months, feed to the unit was limited to no more than 2.5 gpm because of the low DO observations. Excessive amounts of a high strength squash waste were fed unintentionally to the unit on the weekend of November 7-8 and although no DO measurements were taken, it is felt that DO was zero in the tank over the weekend. This conclusion is based on the condition of upset which was evident in the tank thereafter.

Operational characteristics are capsulized in Figure 3. The figure shows COD data from the middle of August (achievement of stabilization) to the end of October. Operation after this period became erratic because of intermittent cannery operation, increased intake clogging problems and the upset after November 8. COD removal is calculated as total COD in minus soluble COD out. It can be seen that in the operating ranges encountered, removal was related directly and essentially equal to the application rate.

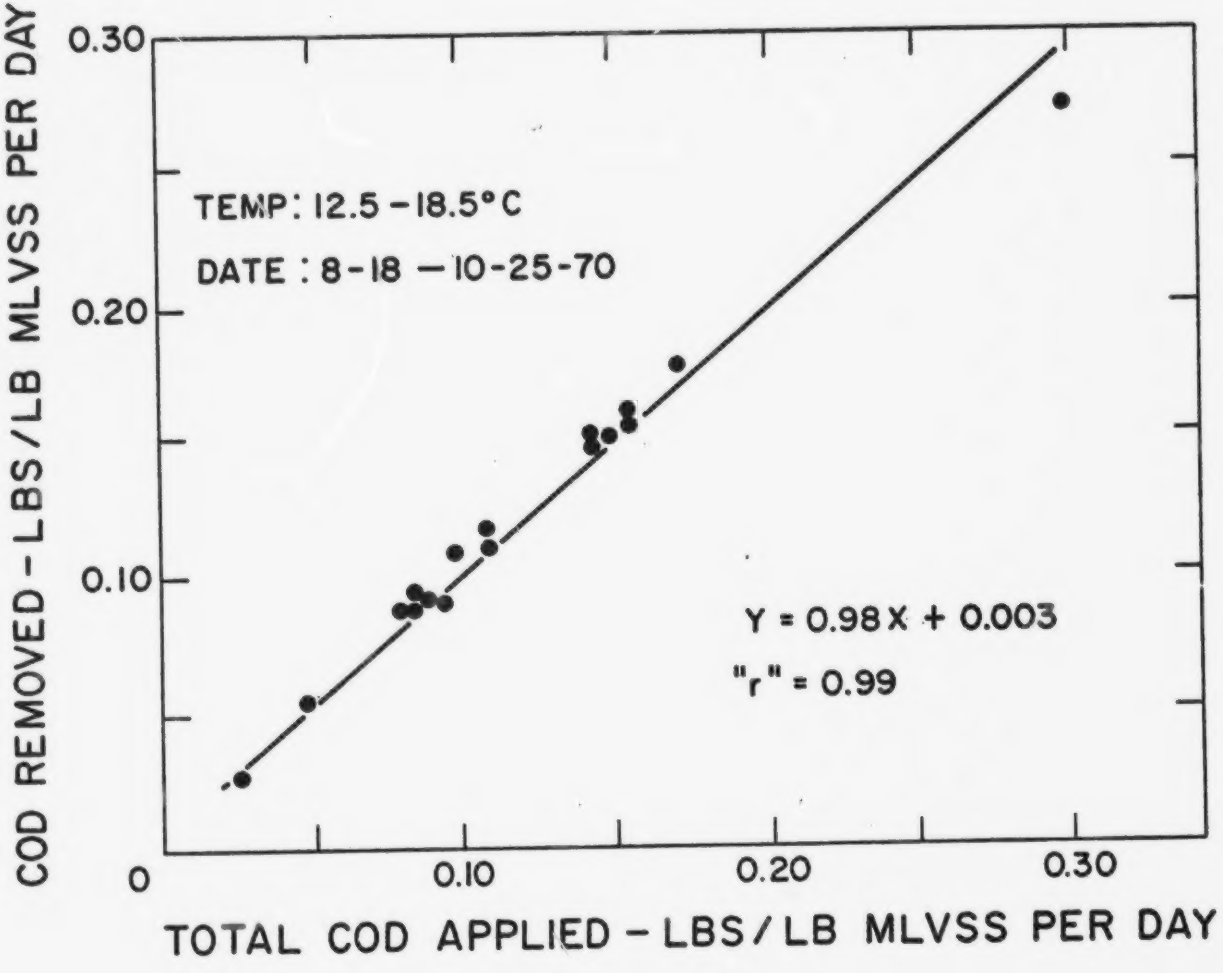


Figure 3. AERATION TANK REMOVAL CHARACTERISTICS CANNERY WASTES

The line shown is a least square line for all the data except one measurement at a maximum loading of 0.3 lbs/lb. Theoretically the percentage removal should start dropping off at higher loadings and this tendency is manifested in the location of this latter point somewhat below the least square line. Higher loadings were not possible because of the limitation in oxygenation capacity.

Discussion

Most discussions concerning the biological kinetics of a waste system of this type are centered around the Monod relationship (1):

$$R = \frac{L_o - L_e}{S_a\ T} = \frac{F\ L_e}{C+L_e} \quad (1)$$

Units are those used in this particular analyses.

R = Reaction rate = waste utilization per unit weight of organisms (days^{-1}).

L_o = Influent substrate concentration = total influent COD or BOD if it is assumed that all suspended volatile matter is biodegradable (mg/l).

L_e = Effluent soluble COD or BOD concentration = substrate concentration in a completely mixed basin (mg/l).

S_a = Mixed liquor suspended volatile matter concentration, which is proportional to the biological mass (mg/l).

T = Hydraulic detention time (days).

F = Maximum waste utilization rate, per unit weight of organisms, at high waste concentrations (days^{-1}).

C = Substrate concentration at F/2 (mg/l).

It can be seen that if L_e is significantly less than C, L_e in the denominator essentially drops out and:

$$R = (F/C)\ L_e = KL_e \quad (2)$$

where K is a constant. Algebraic manipulation of equations (1) and (2) gives the following formula:

$$L_o/L_e = KS_aT + 1 \quad (3)$$

Formula 3 and its variations are fairly well known and often used in designing and evaluating biological treatment systems. It must be remembered, however, that they theoretically should apply only in situations where soluble BOD or COD in the effluent is much less than C.

Three approaches were taken in evaluating the kinetics of the aeration tank; one was a failure, one was of questionable worth, and one gave excellent results for the conditions encountered. The three will now be briefly described. COD values were used in all approaches.

Approach 1

Since L_e levels as high as 125 mg/l were measured in the aeration tank, it was felt that an attempt to determine kinetic coefficients would be more valid if the all-encompassing Monod equation were evaluated rather than the more limited equations (2) and (3). The approach involved the following steps:

1. The basic Monod equation was rearranged and a temperature correction applied to form the following relationship (t = temperature).

$$\frac{(F_{20})(\theta^{t-20})\ L_e}{R} = C + L_e \qquad (4)$$

This was further modified to:

$$\frac{L_e}{R\ (\theta^{20-t})} = (1/F_{20})\ (L_e) + C/F_{20} \qquad (5)$$

Equation (5) can be plotted as the straight line equation:

$$y = mx + b$$

2. Analytical measurements and calculations gave L_e, R, and t values for the various sampling days.

3. θ values between 0.60 and 1.40 were assumed and, with the use of a computer, least square lines and correlation coefficients were calculated using the measured L_e, R, and t values together with the various assumed θ values.

4. The optimum correlation coefficient was determined to be 0.66 and the corresponding θ value was 1.130.

The approach became questionable at this point, for when the θ value was substituted into equation (5), an F_{20} of about 0.3 was produced. This does not approach the values greater than 4.0 which are generally noted in the literature for F. Furthermore, an observed R value during operation was 0.27 at a correspondingly low L_e value which further discredits the 0.3 value. A possible explanation is the high sludge age or solids retention time in the system throughout most of the study; these values were usually between 200 and 300 days and it is questionable whether the assumption that S_a is proportional to the biological mass is valid at these levels.

Approach 2

This method uses equation (2): $R = KL_e$. If a temperature correction is applied it can be modified to the following:

$$\frac{R}{L_e} = K_{20}\,\theta^{t-20} \qquad (6)$$

Equation (6) is the formula for a graphical semi-log plot; R/L_e was plotted against temperature and is shown in Figure 4. A least square line was calculated for the points and it yielded a K_{20} value of 0.00276 and a temperature coefficient of 1.107. Although the K and θ values are reasonable, the low correlation coefficient does not lend confidence to the K and θ values. If a better relationship cannot be developed, the above constants could be used as guidelines at least.

Approach 3

This approach simply involved a comparison of influent unit loading with removal rate and the excellent relationship, previously shown in Figure 3, was developed. The equation of the line relates R directly to a constant times a function of the influent rather than the effluent as is usually done. The data were gathered over a 6°C temperature spread and suggests that $\theta = 1.0$ in this range. Detention times varied between 8.7 and 17.4 days while mixed liquor suspended solids increased from 400 to 2000 mg/l during the data period shown. Influent COD concentration varied between 875 and 3000 mg/l during the same period. In view of the above wide range of variables, the excellent correlation of the data is very remarkable. If a higher aeration capacity were available, the removal rate would have been observed to fall off from the 0.98 relationship. This trend is glimpsed by the slight fall-off of the point representing the highest loading of 0.3 lb/lb-day.

RBC OPERATION

The RBC unit arrived at the Flav-R-Pac cannery during the latter part of August, 1970, and the unit was being fed waste by September 1. Growth developed on the discs within a few days and the initial sampling on September 15 showed that good removals were being achieved.

Feed to the unit was essentially the same waste material as was being sent to the aeration tank, and urea and "9-30-0" fertilizers were added to the unit at levels high enough to assure that a BOD:N ratio equal to or in excess of 20:1 and a BOD:P ratio equal to or in excess of 100:1.

Two restrictions were placed on the operation of the unit. The first involved the rotation speed of 4 rpm which was not adjustable unless the sprocket was changed and possibly a larger drive motor installed. The second limitation involved the DO level in the waste beneath the discs.

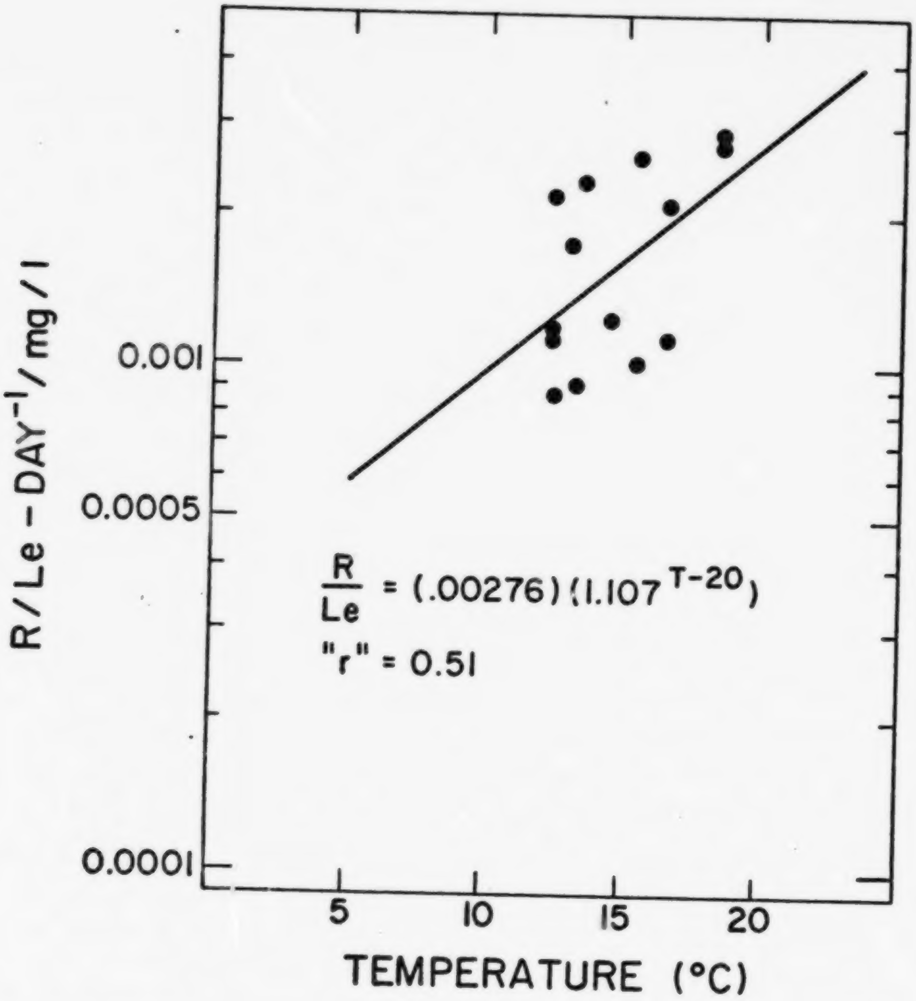


Figure 4. Aeration Tank - Cannery Wastes
R/L_e vs Temperature

Advice was received from Autotrol personnel that some measurable DO should be maintained in this waste. Input to the RBC was therefore limited by the DO level as was the feed to the aeration tank. Recent conversations with Autotrol personnel, however, indicate that the only problem encountered from operation with no DO under the discs might be the presence of odors.

Figure 5 shows the relationship between COD applied to the unit and COD removed by the RBC. COD removal was computed by subtracting the effluent soluble COD from the total influent COD. In order to obtain a common base for comparison between other RBC units, rates are presented per 1000 square feet of disc surface area. The line drawn through the data points is the least square line and the correlation coefficient indicates an excellent relationship. The equation of the line shows that about 95 percent COD removal was obtained throughout the range of loading shown. As loading is increased, the slope of the line will decrease, but the DO limitation did not allow loading up to this level.

Discussion

A major obstacle to the kinetic evaluation of a unit of the RBC type is the inability to determine the amount of active biological mass in the system. The mass is in a dynamic state because of continuous sloughing and if a sample is taken from an outer disc, there is no assurance that the growth in the inaccessible inner disc areas is similar.

An attempt was made to substitute surface area for biomass and subsequently develop a removal rate versus effluent concentration relationship similar to that presented in Figure 4. However, no meaningful relationship was apparent.

A comparison of COD influent loading with removal rate per 1000 square feet gave the very good relationship shown in Figure 5. The removal rate uniformity over the 10-17°C temperature range indicates that θ would be close to 1.0 under these conditions. Detention time during the data gathering period varied from the minimum of 4.1 hours to a maximum of 10.0 hours and influent total COD concentration varied from 875 to 3000 mg/1. Variation of the biomass during the period is, of course, unknown. It can be seen, therefore, that despite a temperature variation of 7°C, influent COD variation of 1:3 and detention time variation of 1:2.5, the basic removal rate remained dependent only upon the amount of COD applied up to at least 10.5 pounds of total COD per 1000 square feet of surface area. Additional observations of the RBC unit will be covered in the next section.

COMPARISON OF THE RBC AND AERATION TANK

The main objective of this study was to determine the effectiveness of the two principles as either complete treatment or pretreatment processes for cannery wastes. Both units have demonstrated their effectiveness under the loading conditions applied. During the study, certain

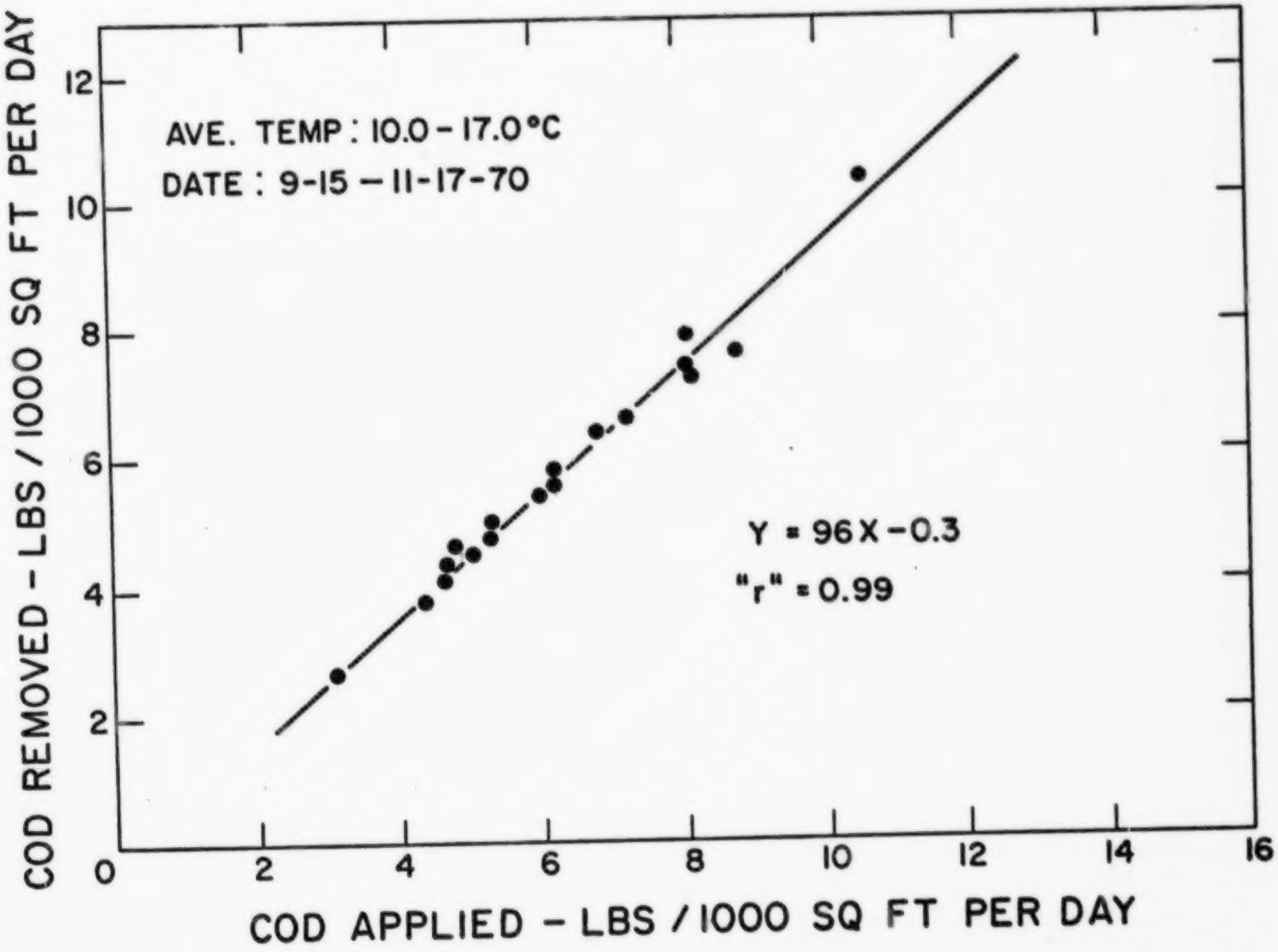


Figure 5. REMOVAL CHARACTERISTICS CANNERY WASTES

characteristics of the two units were revealed which are best covered in this comparative section. Depending on what is being considered, one or the other units seems to be superior.

The U.S. Environmental Protection Agency, in general, and the Pacific Northwest Water Laboratory in particular, do not have the authority to recommend a particular type of waste treatment process over another. This is a decision that must be made by the owner and/or operator of the waste treatment plant or by his consultant. The final decision will depend on the answers to many questions, a number of which would be unique for each special situation. It is hoped that data already presented in this paper and data which will now be presented will assist the owner or consultant in a final decision. Comparative data from the study will now be presented and some questions will be raised in areas in which inadequate data were developed. It is not claimed that all the necessary information which would be considered in a final decision between the two processes is included in this paper.

Detention Time vs. COD Removal

The minimum detention time attainable in both units was dependent on the DO limitations mentioned earlier. As a result the minimum value attained in the aeration tank was 8.7 days based on an average flow of 2.6 gpm. The minimum detention time obtained in the RBC (including the clarifier) was 4.1 hours at an average flow of 2.4 gpm. Measurement of detention time in the RBC is complicated by the amount of space occupied by the biomass but the above value is considered to be within 10 percent of the true value.

Figure 6 compares detention time with COD removal by each unit. The lines are least square lines, but correlation coefficients for both lines were poor. It can be seen that removal shows a tendency to decrease with detention time in the aeration tank. The trend is harder to see in the RBC data for the detention time involved. The most significant feature of the figure is, of course, the fact that the RBC removed the same amount of COD with detention times of only 1 to 5 percent of those observed in the aeration tank.

COD Removal/Horsepower-Day

COD loadings to both units were in the same range throughout the study and removals were also comparable although a much longer detention time was required by the aeration tank, as previously mentioned.

Power to the aeration tank was delivered to the 1-horsepower aerator while power to the RBC was delivered to a half-horsepower motor driving the discs as well as a smaller motor driving the sludge scoop.

Figure 7 relates the COD applied to the power required to remove the COD. Since both units removed similar amounts of COD at similar loadings,

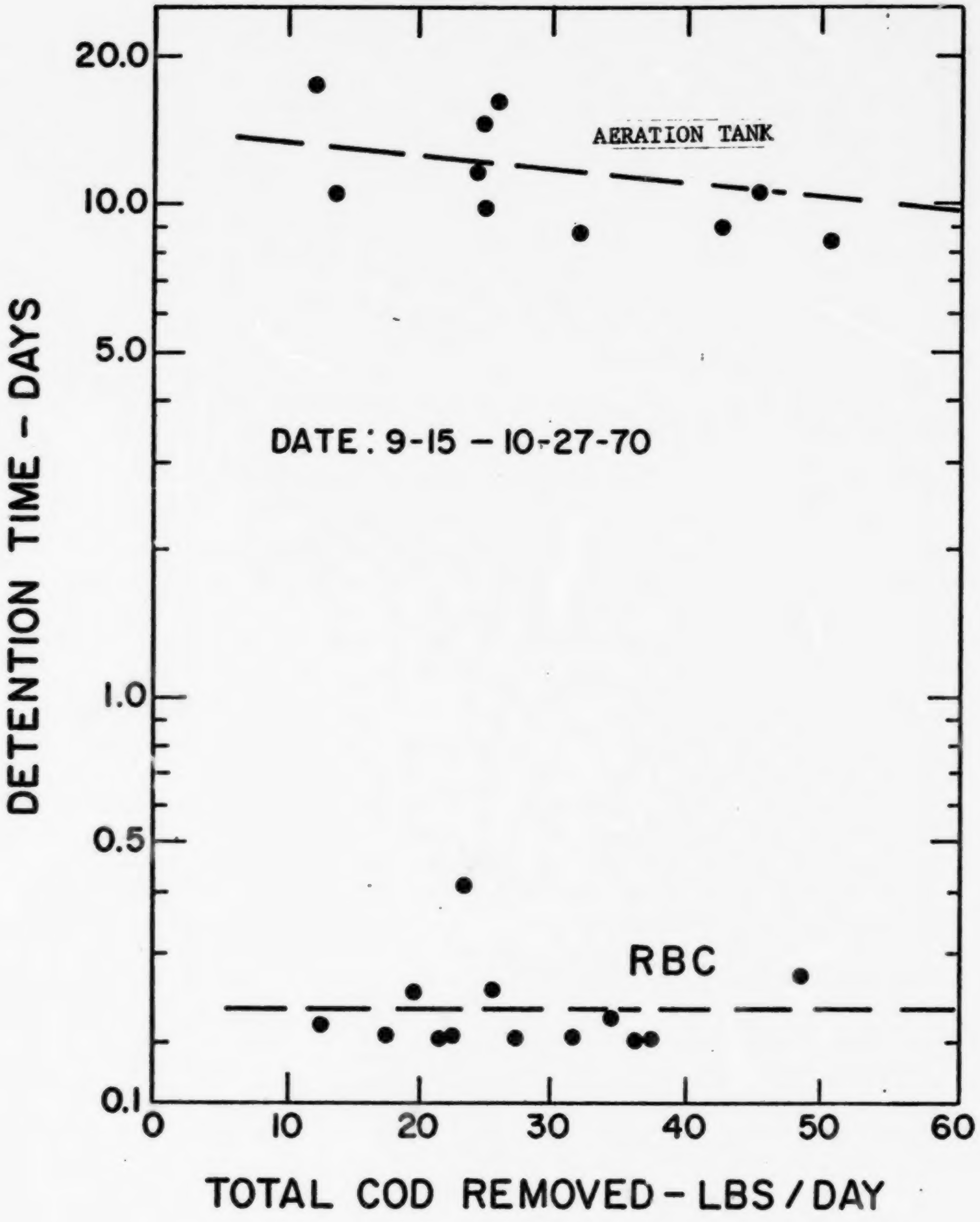


Figure 6. RBC AND AERATION TANK DETENTION TIME VS COD REMOVAL CANNERY WASTES

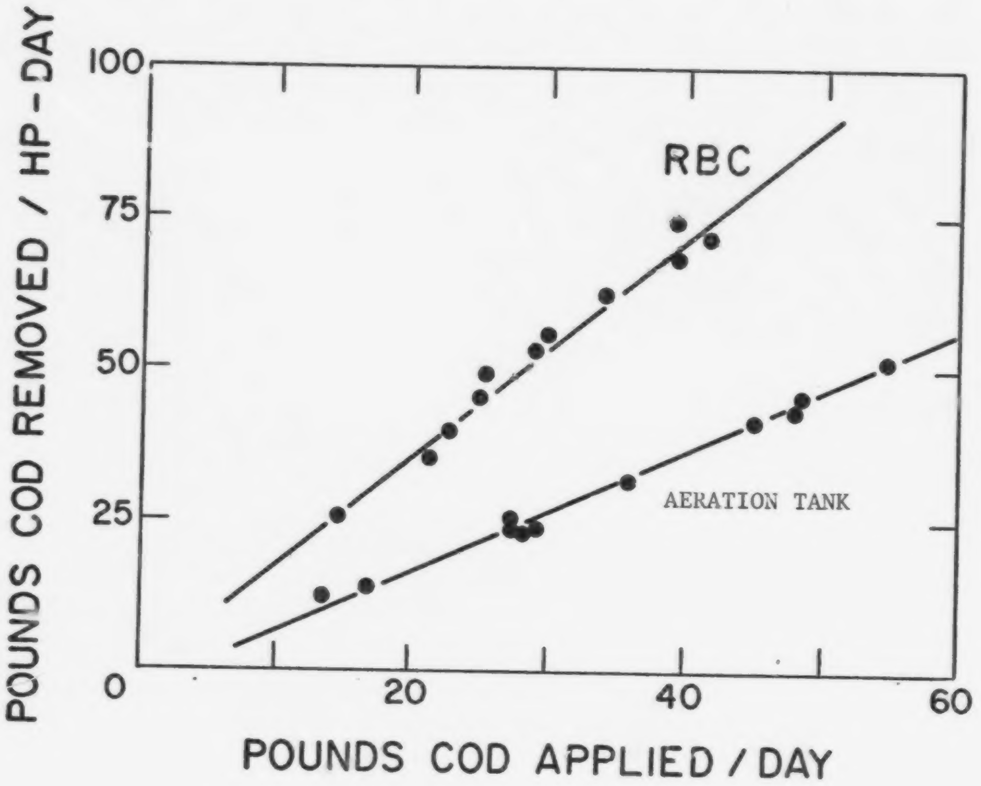


Figure 7. RBC AND AERATION TANK COD ADDED VS COD REMOVED/HP-DAY

the two least square lines actually approximate the horsepower ratios for the two units, i.e. 2:1. It can be seen that the RBC removed the same amount of COD with about 50 percent of the power requirements for the aeration tests.

Figure 7 presents the actual field data but it does not represent an entirely accurate picture of power requirements for the following reasons.

1. Data from the Autotrol Corporation indicate that the half-horsepower disc-drive motor does not operate at capacity until the unit is operated over 6 rpm. Rotation during the study was 4 rpm and data indicate that this speed can be maintained with a power input of 0.1 hp.

2. The 1-horsepower aerator used in this study delivers about 2 pounds of oxygen per horsepower-hour under standard conditions. Aerators above 5 hp capacity will deliver between 3 and 4 pounds of oxygen per horsepower-hour under standard conditions.

It can therefore be seen that data in Figure 7 are conservative and that both systems should remove considerably larger amounts of COD per horsepower in full scale treatment plants.

Effluent Suspended Solids Content

Both treatment devices had clarification capacities which would be considered very adequate for the flow rate encountered. The tube settler in the aeration tank had an overflow rate of 230 gpdsf at 2 gpm of flow and the RBC clarifier exhibited an overflow rate of 190 gpdsf at 2 gpm.

Table 2 gives average effluent suspended and volatile suspended solids values for the two systems during their simultaneous operation. It can be seen that the level of suspended matter in the aeration tank effluent was fairly steady throughout the period from September 15 to November 7.

At that point an upset occurred in the system and mixed liquor solids settleability was reduced to the point that large amounts of solids passed through the tube settler. More will be said about this upset in a subsequent section. Levels of solids in the RBC effluent were more dynamic during the study period with an overall average suspended solids value of 56 mg/l being observed. Average value for the aeration tank effluent, prior to upset, was 72 mg/l. Neither effluent ever approached the clarity that one associates with a well-operated activated sludge plant.

The average values of 56 and 72 mg/l of suspended solids would not be acceptable for discharge into many receiving waters in this country under present or probable future water quality and effluent criteria. However, these values would be quite acceptable for discharge into a municipal sewerage system.

Table 2. RBC and Aeration Tank Effluent Solids Concentrations

Period	Susp. Solids						Vol. Susp. Solids					
	RBC			A. T.			RBC			A. T.		
(1970)	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	n
9/15-9/30	38	31	5	70	16	5	36	28	5	65	16	5
10/1-10/16	93	46	5	72	19	5	65	30	5	63	15	4
10/17-11/7	36	16	5	75	13	3	38	--	2	70	9	3
11/8-11/21	56	45	4	325	143	4	92	--	1	260	104	4

$\bar{x}$ = mean (mg/l)
s = standard dev. (mg/l)
n = no analyses

Sludge Synthesis

In an ideal situation, no synthesized sludge would be discharged from the aeration tank during the canning season and most of the excess sludge would be destroyed by endogenous respiration at the end of the season. Some leakage of suspended matter will always occur, however, and this was observed to be the case with the aeration tank. Most of the sludge was nevertheless observed to be held in the tank until the November 7 upset period. This was evidenced by constantly increasing mixed liquor suspended solids levels and effluent suspended solids concentrations always less than 100 mg/l. The unit, therefore, did operate from August through October as an efficient COD removal system without producing an immediate sludge disposal problem. Ultimately, some inert material would have to be disposed of.

In contrast, the RBC continually produced sludge which on a larger scale operation would have to be disposed of by aerobic or anaerobic digestion, incineration, or other means that will not cause a public nuisance. Sludge synthesis coefficients and settleability characteristics for the RBC sludge were not looked into in great depth. Visual inspections of the sludge showed that it did exhibit good settling characteristics but the RBC effluent suspended solids values showed that separation was not as good as can be achieved with activated sludge.

Temperature Effects

Figures 3 and 5 indicate that both units are not greatly affected by temperature at the relatively mild temperatures in which they were operated. No meaningful data were gathered in the 0-10°C range, but it is anticipated that reaction rates would be significantly lower at this level.

Subfreezing temperatures would hamper the operation of the RBC to the point that it would have to be thermally protected unless the source of the waste was steady and warm enough to prevent freezing. If the unit were used to treat warm wastes for an industry in subfreezing temperatures, operation without insulation could prove satisfactory, but only until a plant shutdown deprived it of the warm water. The rotation increases the heat loss of the liquid and the unit under these conditions would either have to be shut down or it would freeze. Either alternative would destroy the biomass. In contrast, the aeration tank, especially, if it were buried in the ground, would be able to withstand some influent stoppages in subfreezing weather.

Organic Overloads

It would be expected that a short-term organic overload would impair the operation of the RBC because of its short detention time while having little or no effect on the long detention time aeration tank. No short duration overloads were noted but the cannery waste itself changes considerably from hour to hour depending on processing in the plant. Neither unit seemed to be affected by these fluctuations.

A relatively long-term overload occurred on the weekend of November 7-8 when carrot processing was stopped but high strength squash waste continued to be discharged. This caused both units to receive loadings for at least 2 days which were probably far in excess of anything they had received to that point. Inspection of the units on November 9 revealed that they both had been affected. The RBC was observed to be discharging high levels of solid material and the aeration tank was also discharging solids as well as foaming on the surface. DO level in the aeration tank was 0.0 at this time. On the following day, Tuesday, November 10, the routine samples showed that the RBC was functioning as well as ever with good COD removals and low suspended solids in the effluent. The aeration tank continued to discharge solids and its removal rates also dropped off. The aeration tank never recovered and continued to discharge solids until the seasonal shutdown of the cannery on November 24. Mixed liquor suspended solids values in the aeration tank dropped from 2310 mg/1 on November 6 to 1210 mg/1 on November 24 despite the fact that the unit was still being fed fairly high strength squash waste during this period.

The conclusion, of course, is that the RBC demonstrated its ability to "survive" a severe overload while the aeration tank operation was significantly impaired.

Capital Costs

Capital cost comparisons will not be made between the units. The Autotrol Corporation and the suppliers of aerators, liners, etc. will gladly supply this information to anyone interested.

SUMMARY AND CONCLUSIONS

1. The RBC and the aeration-type of treatment are capable of removing most of the organic matter at the levels applied.

2. The RBC removed the same amounts of organic matter as the aeration tank with a detention time of only 1-5 percent of that observed in the aeration tank.

3. The RBC produced sludge which would have to be further processed while the aeration tank did not.

4. Final effluent from both units contained significant suspended matter.

5. Power requirements for the RBC were less than the aeration tanks' requirements.

6. The RBC recovered from heavy shock loadings much more quickly than the aeration tank.

Final decisions on which unit would be more appropriate in a given situation would depend on information given here as well as other factors not mentioned in this paper.

ACKNOWLEDGEMENT

Acknowledgement is hereby given to the following organizations whose contributions of manpower, advice, equipment, and access made the study possible:

Autotrol Corporation

Oregon State University

United Flav-R-Pac Cannery

REFERENCE

1. Monod, J., Recherches sur la croissance des cultures bacteriennes. Paris: Hermann and Cie, 1942.

CANNERY WASTE TREATMENT BY LAGOONS AND OXIDATION DITCH AT SHEPPARTON, VICTORIA, AUSTRALIA

by

Dr. C. D. Parker & G. P. Skerry*

INTRODUCTION

The canning of fruit and vegetables involves the discharge of large volumes of highly polluted wastewater. It is characteristic of these discharges that they are seasonally discontinuous being related to intense canning activity during the usually short period over which each of the various fruits or vegetables ripen. Except where considerable diversification has been made, discharges may only occur over part of the year.

This discontinuity of flow and strength, the high B.O.D. value of many of the wastes, and the rapidity with which the raw wastes develop odour creates considerable difficulty in devising methods of treatment and purification which are nuisance free and effective and at the same time within the financial capability of the industry to accept.

At Shepparton Victoria in Australia there are two large canneries, one Campbells Soup Co. (Aust.) Pty. Ltd. and the other the Shepparton Preserving Company.

Campbell's Soup (Aust.) Pty. Ltd. is a subsidiary of the American Company, they produce meat and general soup products throughout the year, citrus products June to December, and have a large operation with tomato products from February to April.

The Shepparton Preserving Co. is an extremely large canner of apricots, peaches and pears. The cannery handles over 1000 tons of fruit per day and the daily wastewater discharge is over 2 million gallons.

The City of Shepparton has a population of 20,000 persons which means that the problem of purificiation and disposal of the cannery wastes, far outweighs that of sewage purification.

To the domestic sewerage system there are discharged the flows from a butter factory with an 80,000 gallon per day milk intake (manufacturing butter, dry skim milk and casein) an abattoirs slaughtering 2000 sheep per day, a bacon factory and some dairies. The discharge from each cannery is conveyed to the treatment site by independent pipeline separate from the main domestic sewerage system.

---

*Melbourne Water Science Institue Ltd., Water Science Laboratories Melbourne, Australia.

Preceding page blank

The S.P.C. fruit cannery has been in operation since 1932 and until 1965 its wastes have been disposed of by flood irrigation of 70 acres of disposal area.

Campbell's Soup Co. factory was established near Shepparton in 1960 and the Sewerage Authority accepted the responsibility for treatment and disposal of the waste flow.

The problems of constructing effective treatment facilities for the Campbells Soup Co. waste and the ever increasing load from S.P.C., prompted the Authority to undertake a comprehensive study of means of improved methods of treatment.

At the time of the commencement of investigations the general approach to the treatment of cannery wastes was the use of low rate aerobic holding lagoons with odour control by dosage with sodium nitrate and by flood and spray irrigation. An unsuccessful attempt had been made by Norgaard et al (1960) to treat peach and pear wastes by anaerobic fermentation followed by aerobic treatment.

A large plant was subsequently built at San Jose to treat these wastes with domestic sewage by conventional activated sludge.

To have amplified the existing conventional sewage treatment plant consisting of primary treatment with heated digesters followed by trickling filters would have cost many million dollars. Studies were therefore directed towards low cost methods of treatment by lagoons and oxidation ditch. Spray irrigation was also evaluated.

These experimental studies have already been described in detail Parker (1966).

In 1968 a Demonstration Grant was made available by U.S. Environmental Protection Agency to operate facilities made available by Shepparton Sewerage Authority for the treatment of both cannery wastes by a combination of anaerobic lagoon and oxidation ditch.

POLLUTION LOAD AND FLOWS

The present flows and the composition of the major sources of pollution are as shown in Table 1.

It is characteristic of the fluctuations in load that the peak cannery load which occurs in January-April does not coincide with the peak butter factory load which occurs in September-December but is considerably lower than the cannery peak.

INITIAL STUDIES 1962-66

These may be briefly summarized as follows.

Preliminary laboratory model studies established the principles that purification of fruit cannery waste could be achieved by aerobic lagoon

Table 1 Pollution Load

Source	Flow mgd	B.O.D. Load (lbs./day)	Period of Peak Discharge
Sewerage System			
Domestic	1.2	3200	Continuous
Butter Factory	0.15	8000	September - December
Abattoirs	0.30	3600	Continuous
	1.65	14,800	
S.P.C.	2.0	50,000	February - April
Campbell's Soup Co.	1.0	5,000	January - March
	4.65	69,800	

and oxidation ditch provided it were mixed with appropriate quantities of sewage effluent.

Effective operation of an anaerobic type lagoon could be achieved provided the same admixture of waste and effluent were used and provided a frequent regular seed of digested sludge was added. During the 1962 season experimental anaerobic and aerobic lagoons, an oxidation ditch and spray irrigation areas were operated at Shepparton with continuous feed. These experimental facilties confirmed the laboratory established principles and demonstrated approximate permissible loadings for each process. It was concluded that treatment by aerobic lagoon alone would involve very considerable areas, and treatment by oxidation ditch alone would involve very considerable power costs. However, it appeared that if the anaerobic lagoon process were coupled either with aerobic lagoons or oxidation ditch this might prove an effective, acceptable and economic solution.

During the 1963 and 1964 seasons a much larger scale anaerobic lagoon (4 acres) was operated in conjuction with a larger oxidation ditch. These studies demonstrated that a large size anaerobic lagoon loaded at about 600 lbs. B.O.D./ac./day would achieve a 70-80 percent reduction in B.O.D. without any significant odour. Secondly that an oxidation ditch treating an algal laden anaerobic lagoon effluent would achieve effective complete purification and a satisfactory concentration of solids in the ditch could be maintained. Operation of the anaerobic lagoon in series with aerobic lagoons also proved the ability of this scheme to achieve complete purification.

To confirm these findings on a larger scale there was operated during the 1965-66 seasons a 15 acre anaerobic lagoon in series with two large oxidation ditch units. Over this period a number of different rotor designs were evaluated, the performance of one compared with two rotors per ditch was determined and the ability of the ditch to treat raw waste as well as anaerobic lagoon effluent was demonstrated. These studies established that by loading the anaerobic lagoon at 600-800 lbs.B.O.D./ac./day a 70-80 percent reduction in B.O.D. can be achieved and it appeared that this effluent could be treated to reduce B.O.D. to 20-30 ppm. The power requirement for rotor operation would be of the order of 0.30 Kwhr per pound of B.O.D. removed.

Observation of aerobic lagoons into which the excess anaerobic lagoon effluent discharged indicated that at a loading of 80-100 lbs.B.O.D./ac./day the B.O.D. which had been reduced from 3000 to 400 ppm. in the anaerobic lagoon could be reduced to 20 ppm. in the aerobic units.

U.S. EPA DEMONSTRATION GRANT STUDIES 1968-70

Because of the very short fruit canning season and long detention required in anaerobic lagoons, the findings of the above studies have had necessarily to be based on very short periods of observation for the various conditions of loading and operation.

Detailed studies had also been made concurrently concerning the treatment of vegetable canning wastes in anaerobic-aerobic lagoons but not by the anaerobic lagoon-oxidation ditch process.

To determine the long term reliability of lagoon and oxidation ditch processes in the treatment of both fruit and vegetable cannery wastes, the facilities available at the Shepparton Sewerage Authority were operated and observed continuously for two years, supported by Demonstration Grant 12060 EHS

FACILITIES

The facilities used for this study were as follows:

1. Two anaerobic lagoons of 6 and 9 acres, each 4 feet deep, approximately square in shape with three inlets along one side and three outlets along the opposite side.

The flow of raw cannery waste from both the fruit and vegetable cannery and the flow of settled sewage or filter effluent from the sewage treatment plant to the two anaerobic lagoons could be controlled by measured height of flow over V - notch weirs. Daily addition of digested sludge and digester supernatant liquor was incorporated in the sewage effluent flow.

Five other anaerobic lagoon units were available for studies of the influence of nutrient/B.O.D. ratio on performance and six aerobic cells were available to study the behaviour of aerobic cells receiving anaerobic lagoon effluent.

2. Two oxidation ditches each 120 ft. long, 24 feet overall width with two cage rotors 12 ft. long, 27" diameter installed in one ditch and one similar rotor in the second ditch. Water depth in each ditch was 39".

One original experimental rotor was constructed in a manner similar to the original Dutch design but in later units considerable modification was made to eliminate problems with bearing failure, metal fatigue and inadequate oxygenation capacity.

Rotors were operated with 5" immersion of the teeth. The mixed liquor from the oxidation ditch was settled in a conventional circular hopper bottomed sedimentation tank and the sludge returned to the ditches by a Mono pump operated continuously. The sludge return to the two ditches was split according to the waste inflow to each ditch. Excess sludge could be wasted back to the two anaerobic lagoons.

OPERATION & EVALUATION PHASE - ANAEROBIC LAGOON

During the period of the Grant the lagoons treated mixtures of raw sewage or filter effluent together with fruit canning waste or vegetable canning wastes. A summary of the various operations carried out from April 1, 1968 to May 7, 1970, is presented in Table 1.

Table 1 Normal Anaerobic Lagoon Operation

				Influent Composition		
Date	Nature of Waste Treated	Load lbs/acre/day	Percent Removed	B.O.D. ppm.	N ppm.	PO4 ppm.
4/1/68 - 6/1/68	Filter Effluent + Vegetable cannery Waste	190	90	123	25	1.4
6/1/68 - 11/11/68	Raw Sewage + Vegetable cannery + Citrus Waste	360	80	420	60	11
11/11/68- 1/4/69	Filter Effluent + Vegetable Cannery + Citrus Waste	140	85	480	44	27
1/4/69 - 2/7/69	Filter Effluent + Vegetable +Fruit Cannery	227	86	630	37	20
2/7/69 - 6/20/69	Filter Effluent + Vegetable + Fruit Cannery	250	75	580	30	7
6/20/69 - 12/19/69	Raw Sewage + Vegetable Cannery +Citrus Waste	105	80	520	50	23
1/8/70 - 5/7/70	Raw Sewage + Vegetable + Fruit Cannery Waste	600	55 Lagoon 1 40 Lagoon 2	2,100	36	4

One original experimental rotor was constructed in a manner similar to the original Dutch design but in later units considerable modification was made to eliminate problems with bearing failure, metal fatigue and inadequate oxygenation capacity.

Rotors were operated with 5" immersion of the teeth. The mixed liquor from the oxidation ditch was settled in a conventional circular hopper bottomed sedimentation tank and the sludge returned to the ditches by a Mono pump operated continuously. The sludge return to the two ditches was split according to the waste inflow to each ditch. Excess sludge could be wasted back to the two anaerobic lagoons.

OPERATION & EVALUATION PHASE - ANAEROBIC LAGOON

During the period of the Grant the lagoons treated mixtures of raw sewage or filter effluent together with fruit canning waste or vegetable canning wastes. A summary of the various operations carried out from April 1, 1968 to May 7, 1970, is presented in Table 1.

Table 1 Normal Anaerobic Lagoon Operation

				Influent Composition		
Date	Nature of Waste Treated	Load lbs/acre/day	Percent Removed	B.O.D. ppm.	N ppm.	PO_4 ppm.
4/1/68 - 6/1/68	Filter Effluent + Vegetable cannery Waste	190	90	123	25	1.4
6/1/68 - 11/11/68	Raw Sewage + Vegetable cannery + Citrus Waste	360	80	420	60	11
11/11/68- 1/4/69	Filter Effluent + Vegetable Cannery + Citrus Waste	140	85	480	44	27
1/4/69 - 2/7/69	Filter Effluent + Vegetable +Fruit Cannery	227	86	630	37	20
2/7/69 - 6/20/69	Filter Effluent + Vegetable + Fruit Cannery	250	75	580	30	7
6/20/69 - 12/19/69	Raw Sewage + Vegetable Cannery +Citrus Waste	105	80	520	50	23
1/8/70 - 5/7/70	Raw Sewage + Vegetable + Fruit Cannery Waste	600	55 Lagoon 1 40 Lagoon 2	2,100	36	4

April 1, 1968-June 1, 1968

During this period filter effluent from the Shepparton Treatment Plant was combined with vegetable cannery waste and fed to the lagoons at 190 lbs/ac/day. Influent B.O.D. was 123 ppm. and effluent 11 ppm. a removal of over 90 percent. The influent contained 25 ppm. total nitrogen and 1.4 ppm. phosphate which provided adequate nutrients compared with the organic carbon present. The lagoon functioned satisfactorily at a moderate loading under autumn temperatures (12°C.). The green algae Chlorella was present at a level of 400,000 orgs./ml. and dissolved oxygen was present (5 ppm.) in the effluent.

June 1, 1968-November 11, 1968

The Shepparton Sewerage Authority sludge digesters and trickling filters were not operated over this period and the lagoons treated a mixture of raw sewage combined with vegetable and citrus waste. The organic loading on the lagoons averaged 360 lbs.B.O.D./acre/day with an influent B.O.D. of 420 ppm. Over the whole period 80 percent of the applied B.O.D. load was removed. Water temperatures varied from 11°C. in the winter months to over 20°C. in the late spring in October and November. An adequate balance of nutrients was always present with a total nitrogen content of 60 ppm. and phosphorus 11 ppm. The lagoons performed satisfactorily with regard to B.O.D. removal although the algal population dropped to only 40,000 orgs./ml. during July, August and early September, the winter months. It had recovered to 300,000 orgs./ml. by October, with Chlorella being the predominant organism. Dissolved oxygen also disappeared over this period and some sulphide odours developed. In September dissolved oxygen was present in the supernatant but then disappeared until early November.

November 11, 1968-January 4, 1969

The conventional treatment plant provided primary and secondary treatment of the town sewage, so that secondary effluent was combined with vegetable + citrus waste and treated in the anaerobic lagoons. The strenth of the combined wastes was similar to that of the previous period, but the flows available were split between 2 lagoons giving a much lower individual loading of 140 lbs./acre/day with an average influent B.O.D. of 480 ppm. The total nitrogen was 44 ppm. with 27 ppm. of phosphate. 85 percent purification was achieved at this loading with an algal population of 350,000 orgs./ml. (Chlorella). Dissolved oxygen was present in the lagoon throughout this period, and there were no odour problems.

January 4, 1969-February 7, 1969

The composition of the waste over this period was secondary effluent together with vegetable, citrus and fruit cannery waste. The B.O.D. loading on the lagoons was 227 lbs./acre/day with an average removal of 86 percent of the applied B.O.D. Influent B.O.D. averaged 630 ppm. Total nitrogen averaged 37 ppm. with 20 ppm. phosphate, which gave a waste well balanced with regard to nutrient content. The algal population in the supernatant during this midsummer period increased to several million organisms/ml. (Chlorella).

February 7, 1969-June 20, 1969

During the main fruit canning season, which extends over the first 4 months of the year with lesser activity for another 2 months, secondary effluent was combined with fruit and vegetable cannery wastes and fed to the lagoons. The strength of the waste was variable with a peak B.O.D. of 2500 ppm. in March, falling to a few hundred ppm. in the latter part of the season. The average loading was 250 lbs.B.O.D./acre/day. Influent B.O.D. averaged 580 ppm. with 75 percent removal by the anaerobic lagoon. The overall nitrogen content was 30 ppm. with 7 ppm. phosphorus. Algae were at all times present in the supernatant of the lagoons with an average population of 4 million orgs./ml. (Chlorella).

June 20, 1969- December 19, 1969

The fruit canning season had finished and the Sewerage Authority conventional plant had been shut down so that the anaerobic lagoons received a mixture of raw sewage, vegetable cannery and citrus wastes. With only the vegetable cannery oprating, the flows over the second half of 1969 were not high and the lagoon B.O.D. loading was 105 lbs./acre/day. The influent B.O.D. was 520 ppm. with over 80 percent removal of applied B.O.D. Total nitrogen content was 50 ppm-with 23 ppm. of phosphorus. The algal population of 3 million orgs./ml. (Chlorella) was maintained throughout this period indicating that the lagoon was coping easily with the applied loading.

January 8, 1970- May 7, 1970

The usual practice of the sewage authority with the onset of the peak fruit canning season in the early months of the year had been to operate the conventional treatment plant treating the town sewage. Secondary effluent from the plant would then be combined with the cannery wastes and the mixture purified in anaerobic lagoons. In this season it was decided not to operate the treatment plant because of the possibility of odours occurring causing complaints from nearby residents. The Authority was also commissioning a much larger lagoon area consisting of 108 acres of anaerobic ponds followed by 140 acres of aerobic ponds at a new site. Most of the flow was being diverted to the new lagoon area as the new ponds were being brought into operation.

For the remainder of the Grant period the composition of the waste treated was a mixture of fruit cannery and vegetable cannery waste together with raw sewage. The loading over the whole period was 600 lbs.B.O.D./acre/day although the flows were only moderate. The strength of the waste increased from 1500 ppm. B.O.D. in Mid January to between 2500-3500 ppm. B.O.D. until mid April (average 2100 ppm.). Two anaerobic lagoons were being used to treat the waste. The raw waste averaged 36 ppm. nitrogen and 4 ppm. phosphorus. The B.O.D. nigrogen phosphorus ratio was therefore 100/106/0.2 which is not favourable for efficient purification. The B.O.D. removal in the first lagoon averaged 55 percent over the whole season. Total nitrogen of the effluent was 26 ppm. with 24 ppm. phosphates.

In order to improve the nutrient balance of the waste, nutrients in the form of commercial ammonium nitrate and poly-phosphate were added to the second lagoon. 80 lbs. of nitrogen and 8 lbs. of phosphate were added daily to achieve a calculated B.O.D. nitrogen phosphorus ratio of 100/3.5/0.4 which though still low in phosphate would be more favourable for treatment. However, this lagoon achieved only a 40 percent removal of applied B.O.D. Total nitrogen content of the effluent was 33 ppm. with 21 ppm. phosphate.

The addition of these nutrients to the raw waste did not achieve the expected improvement in purification of the waste. Algal population in the first lagoon averaged 1 million orgs./ml. with the predominant organism being Closterium for most of the period.

The algal population in the second lagoon to which nutrients had been added was higher, 2.8 million orgs./ml. (Chlorella).

LAGOON SLUDGE CHARACTERISTICS

Sludge samples were collected at the inlet of the lagoon 30' from the influent pipe, at the middle of the lagoon and 30' from the outlet weir. Sludge depths were measured at 3 points at inlet middle and outlet and the averaged results are presented in summary in Table 2. The Table also includes results of laboratory analysis for total and volatile solids, laboratory purification index and gas yield.

The total solids content of the sludge depended on the depth of sludge at the collection point. A hand sludge pump was used to collect samples and it drew sludge from 1-3 inches above the mud bottom of the lagoon. The amount of volatile solids in the sludge collected varied considerably. In lagoon S_2 the volatile solids were higher at the inlet than the outlet which would be expected but accumulation of the sludge is influenced by the wind direction and at times the effluent sludge had a high volatile solids, indicating movement of sludge from the inlet. The least sludge was always in the middle of the lagoon.

Lagoon S_3 sludges do not show the same pattern. The volatile solids are low during the low loading period of June 1969 and show a higher volatile solids content for the inlet in September 1969, but during the high loading period of 1970 there were in fact higher volatile solids in the outlet sludges, probably again due to wind movement of incompletely digested sludge from the inlets.

The purification index indicates the pounds of B.O.D. removed/acre/day under standardized laboratory conditions by a pound of volatile solids in the sludge sample.

The figures for lagoon S_2 inlet sludge are fairly constant at between 3.5 and 5.0 for most of the samplings apart from a low figure in September 1969.

Outlet sludge shows considerably higher purification capacity than inlet, with sludges collected from the middle of the lagoon having the highest purification capacity as measured by the laboratory test.

The purification index figures are generally lower in S_3 lagoon, but the same pattern is maintained in that effluent sludges show the most activity.

Table 2 Sludge Characteristics

Anaerobic Lagoon (S_2)	Total Solids ppm.	Volatile Solids ppm.	Volatile Solids Percent	Purif. Index	Sludge Depth ins.	Gas Yield mls.gas/day/gm. of Vol. Solids
	Lagoon Inlet Sludge					
6/68	38,200	18,900	50	3.9	10	5.3
11/68	57,940	30,270	52	4.0		2.4
1/69	130,880	30,590	23	3.8		1.0
6/69	88,150	26,380	30	3.2	12	1.0
9/69	59,860	36,780	62	1.4	9	1.0
1/70	41,960	25,690	61	3.5	5	1.2
5/70	59,610	33,060	55	4.8	8	0.6
(S_3)						
6/69	89,350	23,520	26	2.9	9	1.3
9/69	45,320	25,780	57	2.8	9	2.2
1/70	113,250	53,270	47	1.7	4	0.9
5/70	84,940	39,120	46	4.3		0.2
(S_2)	Middle Sludge					
6/68	13,730	6,850	50	11.4		0.9
11/68	17,430	9,220	53	12.5		2.0
1/69	9,320	4,960	53	24		2.2
6/69					3	
9/69	24,100	14,150	59	4.1	3	3.9
1/70	26,490	16,400	62	6.0	3	1.5
5/70	21,880	10,280	47	16.8	4	5.3
6/68	1,480	7,430	50	12.4	8	2.2
11/68	22,130	13,900	63	7.6		5.0
1/69	25,000	12,010	48	10.2		3.8
6/69	65,760	16,880	25	3.8	7	2.2
9/69	35,120	17,110	49	2.1	6	3.8
1/70	52,520	22,520	43	4.0	6	1.0
5/70	62,320	29,620	47	5.5	10	0.9
(S_3)						
6/69	60,390	18,790	31	4.0	6	1.2
9/69	65,910	20,040	30	2.7	8	2.4
1/70	51,340	30,640	60	3.0		1.2
5/70	80,000	45,000	56	3.9		0.3

The gas yield in lagoon S_2 was high at the inlet in the first sampling but then declined to relatively low figures. Several samples of the effluent sludge exhibited greater activity then the inlet.

Gas yields in lagoon S_3 were lower and did not vary from inlet to outlet.

Sludge solids accumulated to some extent during the peak fruit canning season and were not usually digested until the following spring, but by late in the year there was not more than 6-8" of solids accumulated at the lagoon inlet or outlet. These lagoons have been in operation for up to 7 seasons treating in the main fruit cannery waste, so that sludge accumulation is not a problem with this type of waste.

INFLUENCE OF B.O.D./NUTRIENT RATIO ON ANAEROBIC LAGOON PERFORMANCE

Complementary to the nutrient studies on the two anaerobic lagoons feeding the oxidation ditch, further investigations were carried out during the 1969 fruit cannery season with two other lagoons known as T_2 and S_1 which were dosed with S.P.C. waste with two different proportions of sewage to achieve two different ratios of B.O.D. to nutrients.

The results of operation of these two lagoons for this season are shown in Table 3.

Table 3

	Lagoon T_2	Lagoon S_1
Area (ac.)	15	6
Flow (g./d.)		
S.P.C.	209,000	106,000
Sewage	57,000	66,000
Influent load		
B.O.D. ppm.	1,658	1,810
B.O.D. lb./day	4,420	3,120
B.O.D. lbs./ac./d.	294	520
Nitrogen lbs./d.	36	33
B.O.D./N. ratio	134	87
Effluent		
B.O.D. ppm.	310	304
Performance		
Removal		
B.O.D. lbs./ac./d.	240	430
B.O.D. (percent removal)	81	82

It will be seen that lagoon S_1 loaded at 520 lbs.B.O.D./ac/d. achieved the same percentage B.O.D. removal and a removal of 430 lbs./ac./d. compared with lagoon T_2 loaded at only 294 lbs./ac./d. which only removed 240 lbs./ac./d.

The B.O.D./nitrogen ratio for lagoon S_1 was 87/1 or B.O.D./N of 100/1.1 compared with a value of 134/1 or 100/0.75 for lagoon T_2.

These results taken with the observations made with lagoons S_2 and S_3 described above, indicate the significant influence of B.O.D./nutrient ratio in the range 30/1 to 130/1 on performance.

So far no attempt has been made to determine whether further improvement in performance can be achieved by further reduction in ratio below the range observed in these studies.

DETAILS OF OXIDATION DITCH EVALUATION PHASE

During the experimental period an oxidation ditch was run continuously from June 1968 to August 1968, when rotor failure occurred due to faults which had developed in the overall balance of the rotor. Funds were not available for its repair until November 1968 when the damaged section was replaced, stress points eliminated from the whole rotor, and the balance of the rotor carefully checked. After being placed back in operation in January 1969, the rotor then ran continuously until May 1970 apart from a 3 week shutdown in March 1969 when worn water jacketed bearings were replaced with grease packed roller bearings. Using the experience accumulated from the operation of 3 earlier rotors over fruit canning seasons of 4-5 months each, and of the single rotor after 6 months of continuous running, a new improved rotor was designed, built, and put into operation in January 1970. This ran continuously for 4 months without any operational problems or evidence of significant wear.

The various phases of ditch operation and performance are now described.

April 1, 1968 - June 1, 1968

The ditch treated a mixture of filter effluent + vegetable cannery waste at a B.O.D. loading of 45 lbs./day. Influent B.O.D. was 280 ppm. and effluent 9 ppm. a removal of more than 95 percent over the short period of testing. The flow was 120,000 g.p.d. giving a retention time in the ditch of 12 hours. The mixed liquor suspended solids was 1840 ppm. which settled readily. The effluent contained 6 ppm. nitrogen and 1.5 ppm. phosphate. Power consumption averaged 100 Kw.hr./day giving a power B.O.D. ratio of 2.0 Kw.hr./lb. of B.O.D. removed.

June 1, 1968 - June 18, 1968

During this short period the ditch was loaded with raw sewage to build up mix liquor suspended solids and cannery waste. The load applied was 325 lbs./day at an average flow of 109,000 g.p.d. giving approximately 12 hrs. detention in the ditch. B.O.D. removal was over 95 percent with an effluent B.O.D. of 5 ppm. Suspended solids in the mixed liquor were built up to 3,200 ppm. which settled readily.

The effluent contained 7 ppm. total nitrogen and 1.7 ppm. phosphate. Power consumption averaged 110 Kw.hr./day giving a power B.O.D. ratio of 0.3 Kw.hr./lb. of B.O.D. removed.

June 18, 1968 - August 5, 1968

As the lagoon effluent had declined in strength the ditch was operated with a mixture of vegetable cannery waste and lagoon effluent at an average loading of 180 lbs. of B.O.D./day over the whole period with an average removal of 80 percent. Early in July heavy rain occurred at

Shepparton causing a sudden hydraulic overload of the mixed liquor settling tank. A significant proportion of the solids were lost before the excess flow was cut off and mixed liquor suspended solids dropped to 640 ppm. with little purification of the waste load. The ditch recovered rapidly after flows had been cut back and within 2 weeks the mixed liquor suspended solids was 1360 ppm. and the ditch was treating a load of 217 lbs./day achieving a B.O.D. removal of > 95 percent.

August 5, 1968 - February 7, 1969

On the August 5, 1968 an outer section of the cage rotor fractured and jammed the rotor. The rotor was repaired by late December, mixed liquor solids were built up in January and the ditch was placed back into full operation by February 7, 1969.

February 7, 1969 - May 15, 1969

The anaerobic lagoons treated a mixture of filter effluent and vegetable and fruit cannery waste. The ditch purified lagoon effluent at a loading of 120 lbs. of B.O.D. daily. The flow averaged 90,000 g.p.d. giving approximately 16 hours detention in the ditch. The mixed liquor suspended solids content ranged from 1300 ppm. to 4600 ppm. during this period (averaged 2800 ppm.) and settled readily. During this period ditch influent B.O.D. averaged 135 ppm. which was comparatively low due to the effectiveness of the anaerobic lagoon treatment. Effluent B.O.D. however, was 62 ppm. only slightly better than 50 percent removal. Influent nitrogen averaged 30 ppm. with 5 ppm. phosphate and the mix liquor temperature was 20°C., so that the unexpectedly poor performance of the ditch could not be due to lack of nutrients or low temperature. It was noted however, that the algal population in the ditch was 2 million organisms/ml. (chlorella) and it was decided to perform B.O.D. tests after this period on the effluent plus a sample that had been filtered to exclude B.O.D. due to algal decomposition. Effluent nitrogen was 20 ppm. with 4 ppm. phosphate. Average power consumption was 102 Kw.hr./day giving a power B.O.D. ratio of 1.7 Kw.hr./lb. of B.O.D. removed which was not consistent with previous experience.

May 15, 1969 - June 20, 1969

The anaerobic lagoon was still treating filter effluent + vegetable and fruit cannery waste. Because of the decreasing B.O.D. of the anaerobic lagoon effluent (69 ppm. on May 15, 1969). Vegetable cannery waste was added to the ditch to increase the B.O.D. load without hydraulic overload. 190 lbs./day of B.O.D. was added to the ditch with 65 percent removal (influent B.O.D. was 120 ppm. and effluent B.O.D. averaged 40 ppm.). The average flow was 170,000 g.p.d. giving retention time of 8 hrs. in the ditch. In spite of heavy rain on May 29, 1969 mixed liquor solids were maintained at an average of 2400 ppm. during this period. Total nitrogen content of the effluent averaged 20 ppm. with 4 ppm. phosphate. The average power consumption was 102 Kw.hr./day giving a high ratio of 0.85 Kw.hr. of power used/lb. of B.O.D. removed.

June 20, 1969 - December 19, 1969

The anaerobic lagoons treated raw sewage + vegetable cannery waste. The oxidation ditch treated a mixture of raw sewage and lagoon effluent at a loading of 250 lbs. of B.O.D. daily at a flow rate of 99,000 g.p.d. (14 hrs. detention in the ditch). Mix liquor suspended solids averaged 2600 ppm. over this period. The effluent nitrogen content averaged 38 ppm. with 17 ppm of phosphate. The B.O.D. removal averaged 83 percent after algae had been filtered from the effluent. Mixed liquor suspended solids averaged 2600 ppm. over the period. Power usage averaged 87 Kw.hr./day, a much lower figure than on most previous phases meaning 0.42 Kw.hr. were used/lb. of B.O.D. removed.

January 8, 1970 - February 11, 1970

The new rotor had been installed for this period in ditch 1 and both rotors were operated for the remainder of the Grant period (the original rotor was in ditch 2).

The anaerobic lagoons were treating a mixture of raw sewage, vegetable cannery and fruit cannery wastes. The ditches treated a mixture of raw sewage and lagoon effluent. The load on each ditch was 150 lbs.B.O.D./day. The flow averaged 43,000 g.p.d. giving a detention time of 32 hours in each ditch.

Ditch 1 with the new rotor was operated with a higher suspended solids content of the mixed liquor (3860 ppm. average) and effluent B.O.D. averaged 110 ppm. a removal of 62 percent. Effluent nitrogen content averaged 20 ppm. with 15 ppm. phosphate. Because of the low B.O.D. load, power consumed/lb. of B.O.D. removed was 1.1 Kw.hr.

Ditch 2 operated at a mixed liquor suspended solids content of 2050 ppm. and B.O.D. removal averaged 52 percent with an effluent B.O.D of 165 ppm. Effluent nitrogen content averaged 18 ppm. with 17 ppm. phosphate.

The power/B.O.D. ratio was 1.2 Kw. hr./lb. of B.O.D. removed. Over the last week of this period the strength of the lagoon effluent increased sharply as the effect of the high strength fruit cannery waste appeared in the anaerobic lagoon effluent.

February 11, 1970 - May 7, 1970

Both ditches treated anaerobic lagoon effluent from treatment of raw sewage, vegetable cannery and fruit cannery wastes. The load on ditch 1 with the new rotor was 250 lbs. of B.O.D./day with a removal of 70 percent. Because of the extremely high strength of the anaerobic lagoon effluent (1500 ppm.) only 17,000 g.p.d. was treated giving greater than 3 days detention time in the ditch. The suspended solids content of ditch 1 averaged 3230 ppm. with the solids settling readily. Effluent B.O.D. averaged 425 ppm. The nitrogen content of the effluent was 21 ppm. with 24 ppm. phosphate. Power/B.O.D. removed ratio was 0.48 Kw.hr./lb. of B.O.D. removed.

The load on ditch 2 with the original rotor was 230 lbs. of B.O.D./day with a removal of 70 percent. Again the flow was 17,000 g.p.d. giving greater than 3 days retention capacity in the ditch. Suspended solids content averaged 2080 ppm. in the mixed liquor and settled readily.

Effluent B.O.D. averaged 436 ppm. with a nitrogen content of 19 ppm. and 22 ppm. phosphate. Power used/B.O.D. removed was 0.52 Kw.hr./lb. of B.O.D. removed.

DISCUSSION

Performance of Process

The operation of the anaerobic lagoons for two years has shown that a B.O.D. reduction of 75-85 percent can be achieved with loadings up to 400 lbs./ac./day. The period of loading at 600 lbs./ac./day was associated with a very high B.O.D./nutrient ratio and in view of five years experience with other lagoons it is considered that provided the B.O.D./nitrogen ratio is held below 50/1 a load of 600 lbs./ac./day with 80 percent removal (480 lbs.B.O.D./ac./day removed) can be achieved.

Sludge

The capacity of lagoon sludges to remove B.O.D. as measured by the laboratory purification index was reasonably constant for inlet sludges and did not change much with the nature of the waste load or the season of the year. Outlet sludges generally possessed greater B.O.D. purification capacity than those taken near the lagoon inlet. This is in line with previously reported work.

The gas activity of inlet sludges was highest at the beginning of the project and gradually stabilized under the relatively constant B.O.D. loading conditions existing. There was some initial stimulation of gas yield in outlet sludges but this again stabilized to lower figures over the latter portion of the Grant period.

Nutrients

While the main objective of the project was to establish the reliability of the two stage process, some study was made of the influence of nutrients on B.O.D. removal. Operation of lagoons with a range of B.O.D./nitrogen ratio achieved by varying the cannery waste/sewage flow ratio gave definite evidence of increased performance as the B.O.D./nitrogen ratio was reduced below 134/1.

It would appear, although very low ratios were not examined, that the optimum ratio is of the order of 50/1.

Trials in which nutrient ratio was increased by addition of chemicals showed no definite response. The algal population was increased but there was no definite trend with regard to B.O.D. removal.

Oxidation Ditch

The oxidation ditch stage of the process was marred initially by mechanical problems with bearing failure and metal fatigue cracking of the rotor bars. The newly designed rotor used at the latter stage of the project gave trouble free operation over the five month period of use.

The process showed no difficulty in maintaining sufficient solids content in the mixed liquor. It was found that the algal population of the lagoon effluent was carried through to the final effluent.

The B.O.D. removal was consistent with earlier observations and under full load was of the order of 30 lbs.B.O.D./day/foot length of rotor. The power requirement was 0.4-0.5 Kw.hr./lb.B.O.D. removed.

The effect of overload on performance was demonstrated during the second fruit cannery season (1970). Despite an increase in the final effluent B.O.D. to over 400 ppm. a satisfactory fast settling sludge was maintained throughout.

The only operational factor which caused upset to the process was very heavy rain. This raised the level of water over the lagoon effluent weirs inducing a very considerable increase in flow into and out of the ditch. This increased flow through the final sedimentation tank caused sludge to rise over the weir and be lost. However, sludge solids were rebuilt within a matter of two weeks.

Cost Projections

The Shepparton Sewerage Authority was obliged to make a decision concerning the design of new full scale facilities to treat all of both raw cannery wastes and all the city sewage including abattoirs and butter factory after primary sedimentation and sludge digestion at the existing sewage treatment plant, while the demonstration project was in progress. Based on all the earlier experience and the early results of the demonstration project, a decision was made to treat initially by means of the anaerobic-aerobic lagoon system, in preference to anaerobic lagoon-oxidation ditch system. With regard to capital cost there was a slight advantage to the anaerobic lagoon-oxidation ditch but when power costs were considered the annual charge based on local rates of interest and amortization and running costs, the anaerobic-aerobic lagoon system was preferred.

The installation has now been constructed and actual costs are available for the construction of the anaerobic units to treat this combined cannery-sewage effluent flow of 4 m.g.d. with a B.O.D. load of 70,000 pounds per day.

They are as follows:

Land (@ $300/ac.)	$ 35,000
Earth work (@ 35 cents/cyd.)	$ 40,000
Distribution pipes (inlets and outlets)	$ 24,000
	$ 99,000

With regard to oxidation ditch costs, data can be established from those used in the demonstration project. Based on a performance of 30 lbs. B.O.D./day/foot length of rotor and other established design parameters, there would be required in conjunction with the 110 acres of anaerobic lagoons, seven oxidation ditch units of similar dimensions to those observed in the demonstration project.

Concrete work (including channels)	$ 65,000
Rotors, motors and gears (14)	$ 25,000
Electrical	$ 2,000
Sedimentation tank	$ 25,000
Miscellaneous	$ 7,000
Total	$114,000

Running Cost

Power for peak fruit cannery season only 3 months at 2 cents/Kwh.	$ 12,600
Maintenance	$ 5,000 p.a.

Conclusion

Overall the process of treating cannery wastes by anaerobic lagoon and oxidation ditch has demonstrated its reliability and freedom from upset over a two year period of operation. Only one hour per day of maintenance has been necessary.

Cost projections indicate that under Australian conditions an overall B.O.D. load of 70,000 lbs. B.O.D. per day could be purified for a cost of $200,000.

Application

As stated earlier the Shepparton Sewerage Authority was obliged to make a decision in 1968 concerning the design of a full scale facility. On annual cost figures and because of some doubts at the time concerning the mechanical reliability of the rotors for oxidation ditches, a decision was made to treat the wastes initially with the anaerobic-aerobic lagoon process. It was recognized that provided the reliability of the oxidation ditch as a second stage could be established, amplification of the plant to cope with increasing load could be achieved by conversion of some anaerobic units to aerobic units and the second stage facilities amplified by the construction of oxidation ditches. Provision for this development was made during construction.

Discharge to these units first occurred in May 1970 and data is available from that date tothe present concerning the performance of the installation over this initial period of operation.

The whole 24 acres of lagoon holds 370 million gallons and as at present there still remains ponds with capacity of 40 million gallons to fill.

Over the period May 1970 to January 1971 the whole of the settled sewage (containing abattoirs and butter factory waste) and the vegetable cannery waste was discharged first to anaerobic lagoons 1 and 2 and later to anaerobic lagoons 3 and 4. With all four anaerobic lagoons filled and with an increasingly active sludge developed in these lagoons overflow from the anaerobic units filled into the aerobic cells No. 6,7 and 8.

In January 1970 with the commencement of the fruit cannery operation these new facilities have been operated to accept 2/3 of the S.P.D. waste, 3/4 of the sewage flow and 100 percent of the vegetable waste. The overall load on the 110 acres of anaerobic lagoon has been 45,000 lbs.B.O.D./day or 400 lbs./ac./d. and this has now been applied over the last six weeks. The remaining flow has been treated at the existing installation.

The contents of the individual units have had the composition shown in Table 4.

It has previously been shown that anaerobic lagoons take at least one season to reach full activity.

It will be seen that as of the present B.O.D. removal in these new anaerobic units has been over 90 percent at this loading of 400 lbs. B.O.D./ac./day.

It is expected that next cannery season the installation will confortably accept the design load of 600 lbs./ac./day with 80 percent removal.

Conclusion

These investigations extending over nine years have established for the conditions existing at Shepparton, a facility capable of purification of very considerable cannery load together with substantial loads from abattoirs, butter factory and domestic sewage (population equivalent 500,000 persons) for a cost for treatment units of under $250,000.

Table 4 Shepparton Sewerage Authority - New Lagoon Installations

	DB		D_1B		D_2B		D_3B		D_4B		D_5B		D_6B		D_7B	
Date	B.O.D. ppm.	pH	B.O.D. ppm.	pH	B.O.D. ppm.	pH	B.O.D. ppm.	pH	B.O.D. ppm.	pH	B.O.D. ppm.	pH	B.O.D. ppm.	pH	B.O.D. ppm.	pH
6/4/70			33	6.3	20	6.6										
6/18/70			54	7.2	54	7.0										
6/26/70			67	6.7	133	6.5										
7/2/70			94	7.2	105	7.0										
7/9/70	500	6.3	99	7.1	178	7.1	224	7.1	294	7.2						
7/16/70	552	5.6	68	7.2	124	7.2	201	7.3	241	7.4						
7/23/70	416	6.5	94	7.1	169	7.1	109	7.0	261	7.0						
8/6/70	430	6.5	78	7.0	123	6.9	231	6.9	141	7.2						
8/13/70	299	6.4	103	7.0	170	6.9	268	7.0	153	7.4						
8/20/70	256	6.5	77	7.0	102	6.9	284	7.0	123	7.7						
8/27/70	282	6.0	129	6.9	189	6.8	386	6.7	128	7.4						
9/3/70	331	5.7	160	6.7	201	6.5	299	6.7	294	6.7						
9/11/70			107	7.1	140	7.1	128	7.2	158	7.2						
9/17/70	371	5.8	98	6.7	147	6.8	221	6.9	139	7.1						
9/25/70	233	5.9	119	6.9	168	6.9	234	7.0	126	7.2						
10/1/70	206	6.6	129	6.7	144	6.8	204	7.0	134	6.8						
10/8/70	401	5.7	176	6.9	204	6.8	232	6.7	196	6.8						
10/22/70	363	6.8	149	7.0	197	7.1	256	7.0	235	7.0			391	7.0		
10/30/70	278	6.7	134	7.0	153	7.1	184	7.0	349	6.8	146	6.9				
11/5/70	390	6.5	191	6.9	149	6.9	187	7.1	26	7.9			65	7.1		
11/13/70	326	6.8	310	7.1	135	7.1	192	7.0	218	6.8			129	6.9		
11/19/70	383	6.0	131	6.9	119	7.0	112	7.4	49	7.8			30	7.2		
11/26/70	308	5.9	128	7.1	43	7.3	68	7.1	27	7.3			20	7.2		
12/4/70	726	7.0	62	6.9	19	6.8	165	7.1	47	7.2			17	6.9		
12/10/70	726	5.6	45	7.1	11	7.1	76	7.5	130	7.2			16	7.2		
12/17/70	500	6.5	24	7.0	23	7.1	58	7.0	15	8.3			9	7.7		
1/7/71	1088	5.3	13	7.1	8	7.3	28	7.6	35	7.5			5	8.3		
1/18/71	406	6.3	27	6.9	29	7.2	29	7.2	67	7.3			5	7.5		
1/21/71	234	6.0	53	7.1	35	7.3	20	8.0	63	7.7			13	8.2		
2/28/71	530	6.4	46	6.9	152	7.1	89	7.1	24	8.1			24	7.6		
2/4/71	448	6.1	72	7.7	47	7.2	5	8.1	27	6.9			7	8.3		
2/11/71	1192	4.4	86	6.8	92	6.9	102	6.8	41	6.9			6	7.4		
2/18/71	1430	4.5	73	6.9	61	6.9	106	6.6	103	6.9			11	7.3		
2/25/71	1520	5.2	75	6.9	80	6.8	89	6.9	66	7.0			15	7.3		
3/4/71	1000	4.9	91	6.6	81	6.8	74	7.0	74	6.9			50	7.9	18	8.3

BIBLIOGRAPHY

J. T. Norgaard, R. Huks & D. A. Reinsch. "Treatment of Combined Sewage and Fruit Canning Wastes". WPCF Journ. 1088 (1960).

C. D. Parker. "Food Cannery Waste Treatment by Lagoons & Ditches at Shepparton". Proc. 21st. Ind. Waste Conf. Purdue Univ. 284 (May 1966).

C. D. Parker & G. P. Skerry. "Function of Solids in Anaerobic Lagoon Treatment of Wastewater". WPCF Journal 192 (1968).

L. C. Gilde. "Food Processing Waste Treatment by Surface Filtration". Proc. 1st. National Symp. on Food Processing Wastes. Portland Oregon 311 (April 1970).

BIOLOGICAL TREATMENT OF CITRUS PROCESSING WASTEWATERS**

by

Dr. F. A. Eidsness, J. B. Goodson, J. J. Smith, Jr.*

INTRODUCTION

Citrus production, processing, and marketing is a multibillion dollar industry in the United States. The industry is concentrated largely in Florida, which produces about 75 percent of the oranges and 80 percent of the grapefruit grown in the nation. More than 1,300 square miles of the Florida peninsula are planted in citrus trees. The 1967-68 crop from this area amounted to about 9.0 million tons. Future yields will increase steadily with maturity of new groves and additional plantings.

Fifty-two processing plants in Florida in 1965 converted about 82 perent of the citrus crop to single-strength and concentrated juice. Quantities of waste materials from processing operations are quite formidable. The industry has made substantial progress in solving its waste problem through recovery of such valuable by-products as peel, pulp, citrus molasses, and essential oils. However, it was reported in 1965 that the Florida plants discharged about 130 mgd of wastewater with a 5-day BOD loading equivalent to population of some two million people.

Irrigation is widely used in Florida and elsewhere for disposing of citrus processing wastewaters. Economical and technological success for this method of disposal is largely dependent upon favorable site conditions. Disadvantageous locations of its Leesburg and Auburndale, Florida, plants led The Coca-Cola Company, Foods Division, to seek alternate means to eliminate the discharge of untreated wastewaters to the State's surface waters. It was recognized at the time (1962) that there was no generally accepted treatment process for citrus processing wastewaters. Although various biological treatments had been subjected to laboratory and pilot plant studies by a number of investigators; reported results were generally discouraging. Feasibility of a fully co-o.dinated system had not been tested in a single plant-scale venture.

There was a requirement at Leesburg for improvement of the city's primary sewage treatment plant to include secondary treatment facilities, as well as for treatment of The Coca-Cola Company's citrus waste. An estimate of the situation indicated economic advantages for treatment of the combined municipal and citrus wastewaters. Further, it was concluded that requirements of the State regulatory agency might be met by

---

*Respectively, Senior Principal, Principal, and Director of Laboratory, Black, Crow and Eidsness, Inc., Gainesville, Florida.

**Studies sponsored by EPA, Grant No. WPRD 38-01-67 to The Coca-Cola Company, Foods Division.

Preceding page blank

treatment of segregated strong wastes only from the citrus plant. A cooperative program to develop a suitable biological treatment plan on this basis was initiated in August 1962. Laboratory and pilot plant studies involving biological filter and sludge systems were conducted over a two-year period. Based on these studies, a treatment plant of the extended aeration type was installed to accommodate combined city and citrus plant wastewaters. The first-full scale facility of its type in the citrus industry was placed in service during the 1966-67 crop season.

Early in 1967 The Coca-Cola Company, Foods Division, was awarded a demonstration grant by the Environmental Protection Agency. The scope covered studies of the Leesburg treatment system as well as design, construction and testing of a full-scale treatment facility for the Auburndale citrus plant. At Auburndale, all principal wastewaters from The Coca-Cola Company plant and a neighboring Adams Packing Company plant are combined with secondary effluent from the City of Auburndale sewage treatment plant and local storm water in a common public watercourse.

The Coca-Cola Company owns a relatively large amount of land along this watercourse about 0.6 mile below the plant outfall. Circumstances at the time favored a treatment system on this land to treat the large volume of combined dilute wastewaters withdrawn from the channel. An agreement with the Adams Packing Company was entered into, and treatment facilities patterned after the Leesburg system were installed. However, a recognized risk was taken in substituting an earthen settling basin with a simple sludge collection system for conventional mechanical clarifiers, which would have been extremely expensive for flows involved. This full-scale experimental facility was placed in service during the 1968-69 crop season.

Although the Leesburg and Auburndale plants were provided primarily for BOD reduction, it was recognized by the design engineers (Black, Crow and Eidsness, Inc.), that accelerated eutrophication in receiving waters is a problem that must be faced in the future. It was seen also that the facilities afforded an opportunity for investigation of nutrient removal, as well as for further studies regarding factors affecting organics removal.

LEESBURG STUDIES

Objectives

General purpose of studies at Leesburg was to investigate treatment of concentrated citrus processing wastes in combination with municipal sewage. Operating parameters, control limits, and the plant design criteria were of particular interest. Nitrogen and phosphorus relationships were also of interest. Predesign studies indicated that an excess of these nutrient materials in the City sewage would be highly beneficial in compensating for a deficit in the citrus wastewaters.

Description of Wastewaters

The Leesburg citrus processing plant produces citrus concentrate, with by-product citrus molasses, cattle feed, and essential oils. Major sources of high-strength wastewater segregated for treatment are the juice extractors and finisher area, where relatively large volumes of water are used during frequent clean-up periods. Other strong wastes result from less frequent cleaning of juice storage evaporator, blend tank, chiller, and packaging areas. All of these wastewaters, comprising roughly 5 percent of the total wastewater flow, are screened at the citrus plant prior to delivery to the treatment plant. Characteristics of citrus wastes segregated for treatment, after screening, are shown in Table 2. As described in the table, average wastewater is moderately alkaline. Momentary pH values are highly variable and range from about 4 to more than 13. Dissolved solids are comprised of readily biodegradable sugars. Other constituents include peptizing agents, which interfere with clarification; and peel oils, which may act as bacteriostatic agents.

Extensive predesign analyses indicated that raw combined citrus and domestic wastes would contain ample nitrogen for successful biological treatment, with a deficiency of phosphorus. This evaluation was based on generally accepted BOD:N ratio requirements of 15 to 20:1 and BOD:P ratio requirements of 80 to 100:1. Analytical data collected during operation of the plant indicated average ratios of 31:1 and 57:1, respectively.

The usual season at Leesburg extends from early December into June, with a midseason lull between early and late maturing crops. Fruit is processed on a 24-hour per day basis. Weekend operating periods are variable and dependent upon demands.

Average flow of City sewage in 1964 was about 1.15 mgd. BOD amounted to about 145 mg/1.

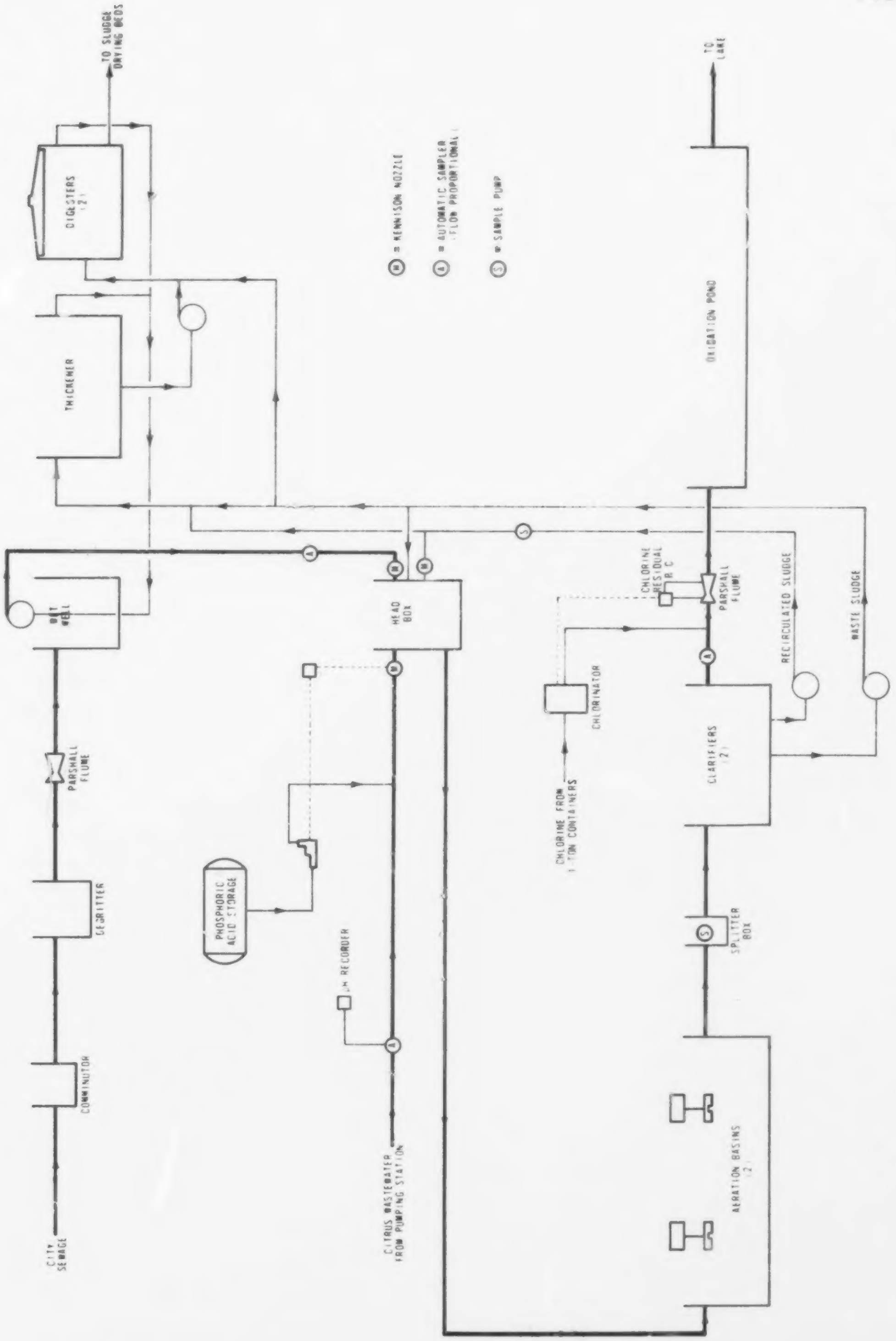
Wastewater Treatment Plant

The plant is a completely mixed activated sludge system providing extended aeration of unclarified raw wastewaters. A shallow oxidation pond was provided for polishing of the effluent. The plant is illustrated in Figure 1, and its various components are described in Table 1.

Plant facilities illustrated across the upper part of Figure 1 are elements of an older primary sewage treatment plant serving the City of Leesburg. The thickener is actually the old primary plant clarifier, with no modifications. As shown in the figure, provisions were made for wasting sludge from the two clarifiers to the thickener. It was anticipated that the thickener and digesters of the old plant would serve well enough to concentrate and store waste sludge prior to dewatering on the drying beds and/or ultimate hauling to a disposal site.

Aerator basins are lined earthen basins. Each was provided with two mechanical aerators, mounted on concrete piers.

FIGURE 1



CITY OF LEESBURG
WASTEWATER TREATMENT FACILITIES
THE COCA COLA COMPANY
FOODS DIVISION
Leesburg, Florida
BLACK, CROW AND EIDSNESS, INC
Engineers

TABLE 1

DESCRIPTION OF
LEESBURG PLANT FACILITIES

Sewerage Facilities:	
Comminutor	
Capacity, mgd	6.0
Degritter	
Type	Air
Capacity, mgd	6.0
Wet Well Pumps:	
Number	2
Drive	Variable speed
Capacity (each), gpm	2,100
Head, feet	40
Citrus Wastewater Facilities:	
Wet well pumps (at citrus plant)	
Low service:	
Number	2
Type	Nonclog wet pit
Capacity (each), gpm	350
Head, feet	15
High service:	
Number	1
Type	Nonclog wet pit
Capacity, gpm	1,000
Head, feet	36
Phosphoric Acid Feeding Equipment:	
Storage tank capacity, gal	1,500
Feed pumps:	
Number	2
Type	Wallace & Tiernan A 747 single head metering
Combined Wastewater Facilities:	
Aeration basins:	
Number	2
Capacity (total), MMG	3.26
Detention (design), hours	24
Aerators:	
Number	4
Type	Mechanical
Horsepower (each)	60

TABLE 1
(continued)

Clarifiers:	
Number	2
Type	Suction (Eimco)
Diameter, feet	55
Detention (design), hours	2.5
Surface overflow rate (design), gpd/sq ft	750
Weir overflow rate (design), gpd/lin ft	10,000
Sludge Recirculation Pumps:	
Number	2
Type	Vertical turbine
Capacity (each), gpm	1,400
Head, feet	25
Waste Sludge Pumps:	
Number	2
Type	Nonclog wet pit
Capacity (each), gpm	150
Head, feet	25
Chlorination Equipment:	
Chlorine storage	1-ton containers
Feeder capacity, lbs/24 hours	1,000
Oxidation Pond:	
Depth, feet (approximate)	3
Area, acres (approximate)	5
Capacity, MMG (approximate)	4.40
Detention, hours (design)	31.5
Thickener:	
Diameter, feet	50
Capacity, gallons	157,000
Digesters:	
Large:	
Type	Floating cover - unheated
Diameter, feet	50
Capacity, gallons	150,000
Small:	
Type	Fixed cover - unheated
Diameter, feet	25.5
Capacity, gallons	76,000
Sludge Drying Beds:	
Area, sq ft	8,590

Plant design data are shown in Table 2. Construction cost, including required modifications only to the old primary plant, amounted to about $500,000.

Plant Performance

The plan of investigation involved series variation of controllable operating parameters during the 1966-67 season and evaluation of results. Delays in completion of plant construction and solving of usual startup problems consumed most of the season. Consequently, the plan was extended to include the 1967-68 season. Full execution of the formal plan was hampered by operational restrictions imposed on the plant. Influent BOD loading, which was not subject to control, was highly variable and frequently exceeded design loading. Primary objective of plant operation was to provide highest degree of treatment at all times. As a result of these factors, the investigation could not be conducted freely as a fully controlled study in the manner of a pilot plant investigation.

Operating data collected during the above mentioned seasons are summarized in Table 2. The table also includes, for comparison, more recent data reported for the month of January, 1971.

The operating data illustrates the plant's remarkable performance with respect to BOD removal. Plant BOD load exceeded design 61 percent of the time during the 1966-67 season, and 20 percent of the time the following season. Despite gross overloads indicated in Table 2, average overall BOD removals of 94 and 96 percent, respectively, were achieved. As shown in the table, average removals exceeded 99 percent recently, with control of loads to design conditions.

In accomplishing above mentioned BOD removals, average unit BOD loading ranged to 28 lbs/day/1,000 cubic feet, with loadings to 72 lbs/day/1,000 cubic feet on a daily basis. It is seen that the average removals of better than 99 percent in January, 1971, were obtained with maximum unit loadings comparable to the design value of 18.3 lbs/day/1,000 cubic feet.

Average plant influent flows were significantly lower than the design flow. Such flows resulted in significantly longer detention periods in the aeration basins than the design period of 24 hours.

Highly variable BOD loadings and other operating problems during the 1966-67 and 1967-68 seasons prevented close control of mixed liquor suspended solids (MLSS). However, the concentration was varied with some degree of success between 1,630 and 6,550 mg/l, as shown in Table 2. It was concluded from the experimentation that the optimum concentration was about 4,500 mg/l, which would yield an inventory of 14 lbs/lb BOD under design conditions. Confirmation is seen in the data for January, 1971, when MLSS concentration was controlled in a range of 4,050 to 4,800 mg/l, and average inventory amounted to 23.2 lbs/lb BOD with a minimum of the order of 15 lbs/lb BOD.

TABLE 2

SUMMARY OF LEESBURG PLANT OPERATION

	DESIGN			OPERATING DATA						
				1966-67 SEASON		1967-68 SEASON		JANUARY, 1971		
	CITY SEWAGE	CITRUS WASTE	COMBINED WASTES	CITRUS WASTE	COMBINED WASTES	CITRUS WASTE	COMBINED WASTES	CITY SEWAGE	CITRUS WASTE	COMBINED WASTES
RAW WASTES:										
FLOW, mgd:										
AVERAGE	2.50	0.85	3.35	0.94	2.05	0.53	1.64	1.37	0.42	1.79
MAXIMUM				1.12		1.63		1.49	0.53	1.92
BOD, mg/l:										
AVERAGE	144	706	287	1,470	782	1,044	409	169	949	343
BOD, lbs/day:										
AVERAGE	3,000	5,000	8,000	11,200	12,200	5,050	6,810	1,940	3,370	5,220
MAXIMUM				29,900	31,400	20,200	22,300	2,620	5,560	7,930
SUSPENDED SOLIDS, mg/l:										
AVERAGE				144	106	148	183	193	198	198
TEMPERATURE, °F.,										
AVERAGE								73	87	
pH VALUE:										
AVERAGE				8.4(1)	8.0	8.0(1)	7.9	8.6	10.6(1)	9.5
AERATION BASINS:										
BOD, lbs/day/M cu ft:										
AVERAGE			18.3		28.0		15.6			12.0
MAXIMUM					72.0		51.1			18.2
DETENTION, hrs										
AVERAGE			24		38		48			44
MLSS, mg/l			2,940	...............1,630 - 6,550.............						4,050 -4,800
MLSS, lbs/lb BOD:										
AVERAGE			10							23.2
SLUDGE VOLUME INDEX				.... 67 - 507.............						200-240
RETURNED SLUDGE, %			100	.... 42 - 184.............						101-125(2)
TEMPERATURE, °F.				.... 66 - 86.............						63-75
DISSOLVED OXYGEN, mg/l				.... 0.1 - 9.0.............						2.2-5.3
CLARIFIERS:										
OVERFLOW RATE, gpd/sq ft			750		447		358			390
EFFLUENT BOD, mg/l										
AVERAGE			29		55					2
RANGE					4-315					1-4
BOD REMOVAL, %										
AVERAGE			90		93					99.4
EFFLUENT SUSPENDED SOLIDS, mg/l					60-210(3)		5-410(3)			1-26
DISSOLVED OXYGEN, mg/l										1-2.2
pH VALUE				.... 7.0 - 10.1.............						8.3-9.6
CHLORINE REQUIRED, lb/day										40
POND:										
EFFLUENT BOD, mg/l					10-47					1-5
BOD REMOVAL, %										
AVERAGE					94		96			99.1
EFFLUENT SUSPENDED SOLIDS, mg/l										
AVERAGE				.... 32						14
DISSOLVED OXYGEN, mg/l				.... 0.2 - 31.............						5.3-14.8
TEMPERATURE, °F.				.... 61 - 90.............						57-70

---

(1) MOMENTARY pH VALUE OF CITRUS WASTE EXTREMELY VARIABLE - 4 TO 13+.

(2) WITH AVERAGE SUSPENDED SOLIDS CONCENTRATION OF 6,980 mg/l.

(3) RANGE OF WEEKLY AVERAGES.

As seen in Table 2, relatively high sludge volume indices result from treatment of the combined wastewaters. This was attributed to filamentous organisms (Sphaerotilus) resulting from high carboyhdrate content of the citrus waste.

It appeared from the two seasons of study that optimum sludge recirculation rate would be somewhat less than 100 percent of influent flow. Rates of 101 to 125 percent, with average recirculated sludge solids concentration of 6,980 mg/l, evidently were satisfactory in January, 1971. First cost economy of the vertical turbine pumps installed for sludge recirculation was outweighed by operating problems and maintenance. Outages resulted from fouling of impellers and bearings. Stringy solids, such as hair, were particularly troublesome with bearings. It became necessary to substitute more conventional sludge pumps.

Plant influent flows to date have resulted in average clarifier surface overflow rates significantly below the design rate. Yet solids carryover from the clarifiers has been a rather persistent and troublesome problem, as evidenced by clarifier effluent suspended solids data in Table 2. The problem stems from the characteristic high SVI of the sludge, but it is aggravated by surging. As indicated in the table, the carryover was much more pronounced during the 1966-1967 and 1967-1968 seasons, when treatment control was extremely difficult due to bizarre loading conditions. Recent loadings are much closer to design and afford more consistent control. As evidenced by the January 1971, data, carryover has been reduced to reasonable limits. However, the data indicate more conservative design criteria for clarifiers in similar systems. In addition to lower design overflow rates, consideration should be given to deeper clarifiers and designs to minimize disturbances of the very delicate flocs.

It is seen from Table 2 that the pond was quite effective in compensating for deficiencies in treatment process control. Near design conditions in January 1971, afforded effluent BOD values of 1 to 5 mg/l and high dissolved oxygen concentrations. A study of pond ecology in 1969 indicated a balanced biota of a type desirable in the receiving lake water.

Limited data indicated production of waste sludge solids amounting to about 0.4 to 0.6 pounds per pound of influent BOD. It was shown that waste sludge could be thickened to a solids concentration as high as 3.2 percent with facilities provided. Thickened sludge dewatered well, with no odor, on the drying beds. However, estimated bed capacity of 7,500 gpd was inadequate for handling all waste sludge. It was found necessary during the 1967-1968 season and during January 1971, to haul away for disposal some 20,000 gpd of the thickened sludge.

Supplemental nutrients were found to have no effect on treatment efficiency and are no longer employed at the plant. Nitrogen and phosphorus removals through the system averaged 70 and 90 percent, respectively. Waste sludge removed from the treatment system accounted largely for the removals.

Principal Conclusions

1. Activated sludge process of extended aeration type is capable of a high degree of treatment of combined municipal and citrus processing wastewaters.

2. Design should be based on a MLSS inventory under aeration of about 14 lbs/lb of daily BOD, which yielded a MLSS concentration of 4,500 mg/l at Leesburg.

3. High sludge volume indices are characteristic of citrus processing wastewaters.

4. An extremely conservative surface overflow rate is required for secondary clarifiers, and design should include extra depth and afford minimal internal turbulence.

5. Flow equalization and minimization of surging should be accommodated to the fullest extent in the design.

6. Waste sludge facilities should be designed on the basis of about 0.6 pounds dry sludge solids per pound of influent BOD.

7. A polishing pond is advisable.

AUBURNDALE STUDIES

Objectives

Studies at Auburndale dealt with treatment of total effluent from citrus processing operations. Initial purpose was to evaluate design and operation of a Leesburg-type system, modified to afford economical treatment of the much larger flow of weak wastewaters at Auburndale. Objectives were broadened later to embrace an investigation of an aerated lagoon system for treatment of the wastewaters.

Treatment kinetics and supplemental nutrient requirements were considered in the investigation. Further studies pertained to nutrient removal by aquatic plants, with ultimate disposal of the plants in cattle feed.

Description of Wastewaters

The Coca-Cola Company, Foods Division, plant at Auburndale produces citrus concentrate and "Hi-C," beverage. Neighboring Adams Packing Company plant produces concentrate, single-strength juice, and sectioned fruit. Both plants produce by-product citrus molasses, cattle feed, and essential oils. In each plant the wastewaters are screened for gross solids removal prior to discharge to Lake Lena Run, which accommodates local drainage. Effluent from the City of Auburndale secondary sewage treatment plant also enters the watercourse in the vicinity of the citrus plant outfalls. These combined wastewaters are diverted from the run into The Coca-Cola Company's treatment facilities, located downstream.

Wastewater flow from The Coca-Cola Company is of the order of 20 mgd, with a BOD concentration of about 120 mg/l. Adams Packing Company effluent amounts to some 10 mgd with a BOD concentration around 190 mg/l. The City of Auburndale sewage flow is approximately 0.76 mgd. Industrial wastes in the sewage contain appreciable amounts of formaldehyde and other toxic materials. Nutrient levels in the combined wastewater were variable and generally marginal for optimum biological treatment. Characteristics of raw wastewaters diverted to treatment during the studies are shown in Table 4.

Whereas the usual season at The Coca-Cola Company plant extends from December through July, that at Adams Packing Company runs from November through July. Both plants operate on a basis of 24 hours per day with a period of diminished processing about midseason.

Wastewater Treatment Plant

Treatment of facilities are illustrated in Figure 2 and described in Table 3. As in Leesburg, the system was designed for extended aeration of unclarified raw wastewater in a modified activated sludge process. However, notable exceptions were employed for sake of economics in accommodating the much greater hydraulic loadings.

All basins and ponds are unlined. Site conditions dictated pumping to achieve flow through the system. The arrangement shown in Figure 2 was selected to minimize the cost for pumping facilities. Wastewater is diverted by gravity from the stream into the aeration basin. Low lift, irrigation type propeller pumps mounted above the opposite end of the basin transfer wastewater, including recirculated flow, to the settling basin. Flow from this point, including recirculation to the aeration basin, is accomplished by gravity. Mechanical aerators are float-mounted to adapt to variations in basin water level.

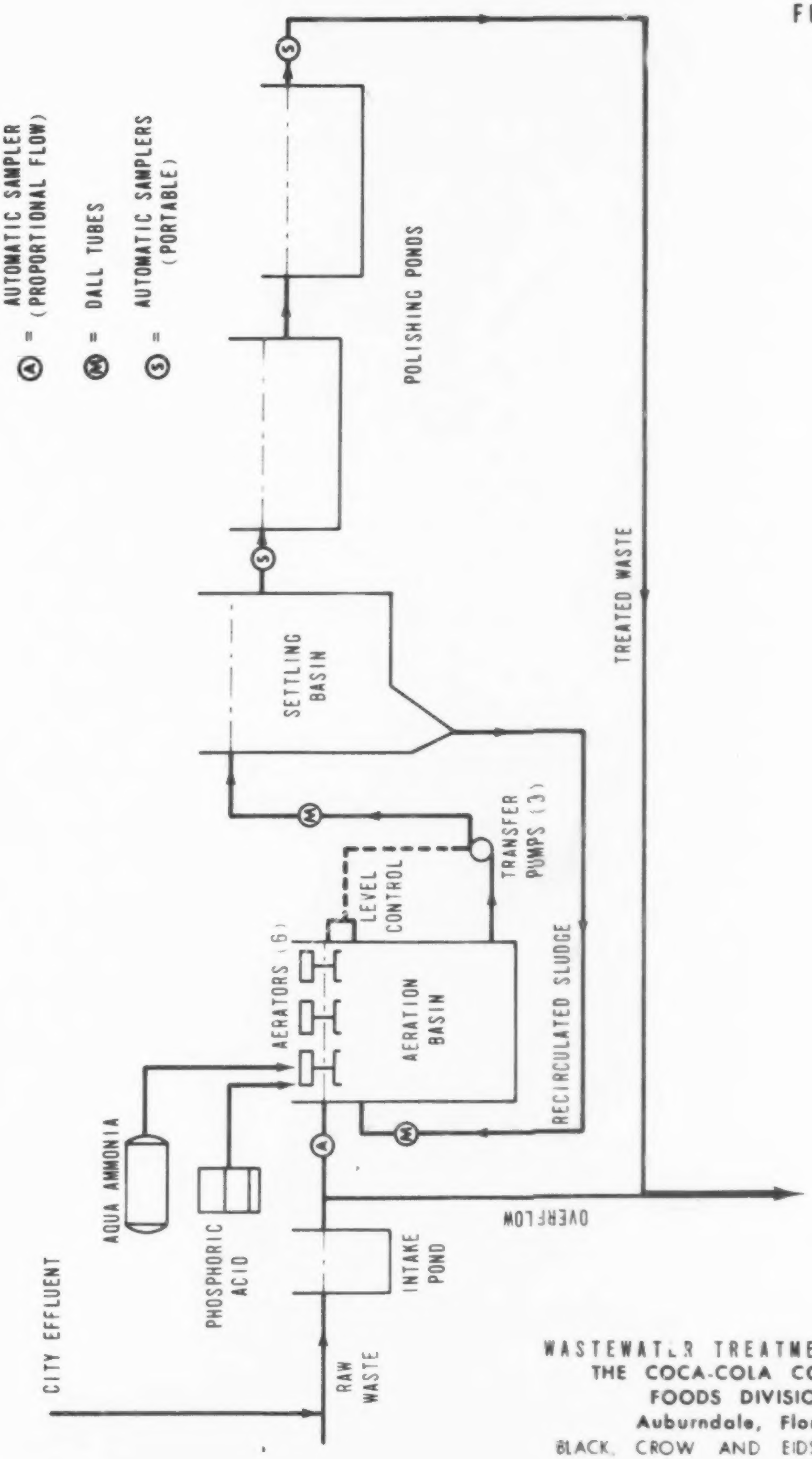
The earthen settling basin, arranged for gravity collection and transfer of sludge, was substituted for conventional clarifiers as another economy measure. It was conceded that its efficiency would not match that of conventional equipment, but it was believed that it might suffice for maintaining an acceptable concentration of solids in the aeration basin. The experiment was recognized as a risk by the owner. A distribution trough across the end of the basin equalizers flows down the basin. The floor at the inlet end slopes 15 degrees to form a large transverse trough. A perforated pipe was provided in the trough for collection and transfer of settled sludge.

Plant design data are shown in Table 4. Construction cost amounted to about $485,000.

Plant Performance

Plant performance during the 1968-1969 season is described in Table 4. Exploratory work involving plant operation was divided into three periods. The first period was devoted to the modified activated sludge process,

FIGURE 2



WASTEWATER TREATMENT PLANT
THE COCA-COLA COMPANY
FOODS DIVISION
Auburndale, Florida
BLACK, CROW AND EIDSNESS, INC.
Engineers

TABLE 3

DESCRIPTION OF AUBURNDALE PLANT FACILITIES

Aeration Basin (Earthen)	
Area (water surface), acres	3.15
Water depth, feet	11.7
Capacity, MMG	9.70
Detention (average), hours	15
Aerators	
Number	6
Type	Mechanical (floating)
Horsepower (each)	75
Nutrient Feeding Equipment	
Phosphoric acid (85% H_3PO_4):	
Storage capacity	40 gal. drums
Pump type	Wallace & Tiernan A 747
Pump capacity, gpd	22
Ammonia (Aqua - 29% NH_3)	
Storage tank capacity, gal.	8,000
Pump type	Wallace & Tiernan A 748
Pump capacity, gpd	960
Transfer Pumps	
Number	3
Type	Propeller
Capacity, mgd	Two - 16.74 (each) One - 9.33
Recirculation capability, % of average flow	174
Settling Basin (Earthen)	
Sludge collection section:	
Area (water surface), acres	2.72
Overflow rate (average), gpd/sq ft	132
Water depth, feet	14.2
Capacity, MMG	9.21
Detention (average), hours	14
Total Basin	
Area (water surface), acres	6.78
Capacity, MMG	20.77
Detention (average), hours	32

TABLE 3
(continued)

Polishing Pond No. 1 (Earthen)	
Area (water surface), acres	6.85
Water depth, feet	5.0
Capacity, MMG	10.55
Detention (average), hours	16

Polishing Pond No. 2 (Earthen)	
Area (water surface), acres	6.85
Water depth, feet	4.5
Capacity , MMG	9.55
Detention (average), hours	15

Total Pond System	
Area (water surface), acres	23.6
Capacity, MMG	50.6
Detention (average), days	3.24

TABLE 4

SUMMARY OF AUBURNDALE PLANT OPERATIONS

		AVERAGE OPERATING DATA(1)		
	DESIGN	DEC. 1968 - FEB. 1969(2)	MAY 1 - 19, 1969(3)	MAY 20 - JUNE 19, 1969(4)
RAW WASTE:				
FLOW, mgd	15.6	15.0	5.3	9.5
MAXIMUM	30.0	26.5	6.1	13.6
BOD, mg/l	142	114	134	149
BOD, lbs/day	18,500	14,200	5,920	11,800
MAXIMUM		30,900	11,400	26,300
SUSPENDED SOLIDS, mg/l		27	18	26
TEMPERATURE, °F		79	85	92
pH VALUE		7.1	7.1	7.0
AERATION BASIN:				
BOD, lbs/day/M cu ft	14.3	11.0	4.6	9.1
MAXIMUM		24.0	8.8	20.3
DETENTION, HOURS	14.9	15.5	44	24
MLSS, mg/l	2,300	66	49	68
MLSS, lbs/lb BOD	10	0.38	0.67	0.47
RECIRCULATION, %	174	65(5)	91	108
MINIMUM	43			
DISSOLVED OXYGEN, mg/l		3.3	6.0	4.9
SETTLING BASIN:				
DETENTION, HOURS	32	33	94	52
EFFLUENT BOD, mg/l		55	19	33
BOD REMOVAL, %		61	86	78
EFFLUENT SUSPENDED SOLIDS, mg/l		44	44	37
DISSOLVED OXYGEN, mg/l		0.9	1.7	1.3
pH VALUE		7.1	7.3	7.1
POLISHING POND NO. 1:				
DETENTION, HOURS	16	17	48	27
DISSOLVED OXYGEN, mg/l		0.4	2.4	1.5
POLISHING POND NO. 2:				
DETENTION, HOURS	15	15	43	24
DISSOLVED OXYGEN, mg/l		1.4	2.9	1.5
TEMPERATURE, °F		72	79	84
pH VALUE		7.1	7.9	7.3
EFFLUENT SUSPENDED SOLIDS, mg/l		31	9	26
EFFLUENT BOD, mg/l		42	7	24
OVERALL SYSTEM:				
DETENTION, DAYS	3.2	3.4	9.5	5.3
BOD, lbs/acre/day	784	602	251	500
BOD REMOVAL, %		67	95	84

---

(1) UNLESS OTHERWISE INDICATED.

(2) TOTAL WASTE FLOW ADMITTED TO PLANT.

(3) PLANT INFLUENT FLOW LIMITED TO 5± mgd.

(4) PLANT INFLUENT FLOW LIMITED TO 10± mgd.

(5) WITH AVERAGE SUSPENDED SOLIDS CONCENTRATION OF 53 mg/l.

in accordance with initial objectives of the investigation. In remaining periods, the plant was operated as an aerated lagoon system to satisfy broadened objectives.

Operations during the December-February period, involving treatment of all wastewater, showed that the plant was incapable of the design modification of the activated sludge process. Despite a wide range of controlled operating conditions, MLSS concentration did not exceed 200 mg/l and averaged about 66 mg/l. Equivalent MLSS/BOD ratio was only 0.38. Failure was attributed to inadequacy of the experimental sludge collection system in the settling basin. However, average BOD removal through the settling basin amounted to 61 percent, and overall removal was 67 percent. Such removals for loadings involved proved to be in the range expected of an aerated lagoon system and suggested studies in that regard for the remainder of the season.

During the period of May 1 - 19, plant influent flow was controlled to an average of 5.3 mgd. As shown in Table 4, average BOD removal through the clarifier was 86 percent, and overall removal was 95 percent. From May 20 through June 19, influent flow was increased to an average of 9.5 mgd. Average BOD removals for above described locations amounted to 78 and 84 percent, respectively.

Kinetic studies on the wastewater, using acclimated sludge, yielded BOD removal rate coefficients ($k_{20°C}$) ranging from 0.80 to 2.80 and averaging 1.46. Temperature coefficient (θ) was found to vary between 1.04 and 1.06, with an average of 1.05.

Water collected during the investigation indicated maximum flow and BOD loading to be about 30 mgd and 32,500 lbs/day, respectively. Based on studies described above, it was estimated that improvements involving 40 acres of aeration basin and 450 horsepower in mechanical aerators would be required for these maximum conditions. Such improvements would be expected to yield BOD removals of better than 90 percent.

Raw waste average BOD:N ratio was 37:1 and average BOD:P ratio amounted to 144:1. It was confirmed by ecological studies during the investigation that a BOD:N:P ratio of 150:5:1 afforded a well balanced biological system for treatment of the waste. Nitrogen and phosphorus reductions during treatment were about 21 and 26 percent, respectively.

Nutrient Removal by Aquatic Plants

A portion of Polishing Pond No. 1 was isolated for controlled studies pertaining to nutrient uptake in water hyacinths. These studies indicated that at least five days' detention is required for significant removals. Best removals were obtained with dissolved oxygen concentrations below 0.5 mg/l. Average removals with five days' detention and dissolved oxygen concentration of about 1.0 mg/l amounted to 22 percent for nitrogen and 36 percent for phosphorus. As a matter of some interest, BOD removals amounted to about 70 percent.

Processing of harvested hyacinths by squeezing and drying yielded 34,000 gallons of press liquor per acre of hyacinths. Nitrogen and phosphorus content of the liquor was 335 and 63 mg/l, respectively. Citrus plant feed mill equipment would require extensive modification for incorporation of hyacinth processing. Processed hyacinths were similar to alfalfa hay in food value.

Principal Conclusions

1. The existing low cost Auburndale facility will not accommodate an activated sludge process due to inadequacy of the experimental sludge collection system.

2. High volume - low strength wastewaters from citrus processing are amenable to a high degree of treatment in an aerated lagoon system at BOD loadings of the order of 550 lbs/day/acre.

3. Hyacinth ponds affording detention times of the order of 5 days offer moderate nutrient removals. Although hyacinths show promise as a cattle food supplement, processing presents substantial problems.

TREATMENT OF MEAT PACKING WASTE USING PVC TRICKLING FILTERS

by

Darrell A. Baker* and James White**

PROJECT DEVELOPMENT

In the summer of 1968 Burns & McDonnell Engineering of Kansas City, Missouri was approached by Farmland Foods, a subsidiary of Farmland Industries, Inc., Kansas City, Missouri, a farmer owned cooperative, for the specific purpose of designing a waste treatment plant for our Denison, Iowa, pork operation. Several limitations account for this particular type of plant, but foremost was the land available for such a plant. In short, this plant was designed specifically for the minimal land available.

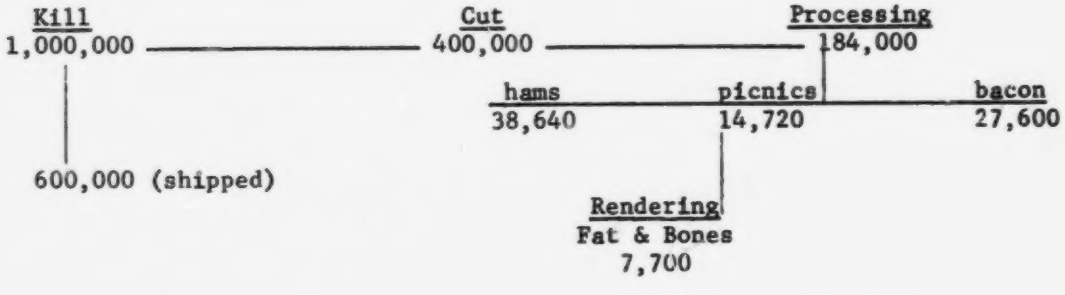
Shortly after the inception of the plan the Environmental Protection Agency, then F.W.P.C.A. was approached for possible funding of the treatment plant construction. The construction phase of the project began in April, 1969 with E.P.A. participating in the project in the amount of $290,000.

PLANT DESCRIPTION

The plant is located N.W. of Denison, Iowa, which has a population of 6,500, and has the capacity to kill and dress 5,000 hogs per day. The hog cut operation generally accounts for about 40 percent of the kill plus two or three hundred head per day from our Iowa Falls plant. Processing as hams, picnics, bellies (bacon) accounts for about 46 percent of the 40 percent above. The following line diagram illustrates the breakdown:

ILLUSTRATION I

BREAKDOWN OF PLANT PROCESSES(lbs.)



---

*Farmland Foods, Inc., Denison, Iowa.

**Allen Wymore, Burns & McDonnell Engineering, K. C., Mo.

Preceding page blank

The waste from the plant is typical of most packing house operations, having high BOD, grease and solids content, with variable pH and temperatures. The waste from the plant is collected in two main lines, one line accepting all wastes from the kill floor area except the scald tank; the other line accepting wastes from the hog pens, scald tank, rendering, blood drying operation, and the domestic waste. There is no cooling water entry into either line.

Plant Units:

The waste from the No. 1 main sewer line is pumped into an air flotation cell for pretreatment before going into the anaerobic lagoons. The grease removed from the flotation cell is sent back to be rendered and sold as brown house grease.

The flotation effluent and the other sewer discharge combine shortly before discharging into the anaerobic lagoons which are operated in parallel. The anaerobic lagoons serve two functions, the first being biological treatment of the wastes and the second that of acting as holding lagoons to distribute the flow to the filter plant evenly throughout the work week. The plant generally operates on a 5 or 6 day work week; for this reason an appreciable difference in flows may be noted on the weekends.

The effluent from the anaerobic lagoons flows through a control valve which can be operated manually or automatically; then through a preaeration tank which serves two purposes; to control odors emanating from the anaerobic effluent, since the plant is relatively close to a residential area, and to supply a limited amount of oxygen to the waste before treatment by the trickling filters. Presently a masking agent is being used intermittently to control odors in the anaerobic effluent. The preaeration tank effluent is then pumped to the trickling filters normally operated in series; then to the final clarifiers, and then to a chlorine contact basin for disinfection. Sludge removed from the final clarifiers is recycled to the anaerobic lagoons.

DESIGN CRITERIA

A summary of design criteria for the treatment facilities is shown in Tables 1 through 8.

Table 1 Raw Wastes Criteria

Hogs Killed Per Day	5,000
BOD Loading:	
5,000 Hogs Kill at 4.3 pounds	21,500 lbs./day
Average Waste Flow:	
Gallons per Hog	175 gal./hog
Gallons per Day	850,000 gpd
Maximum Daily Flow	1,000,000 gpd
Peak Hourly Flow	1,500,000 gpd

Table 2 Air Flotation Tank Design Criteria

Diameter	22'-6"
Water Depth	12'-0"
Hydraulic Rate	1500-gpm
BOD Removal	40%
Grease Removal	85%

Table 3 Anaerobic Lagoon Design Criteria

Number of Cells	2
BOD Applied, lbs./day	12,900
Design loading, lbs. BOD/1000 ft^3	15
Water Depth, ft.	14
Surface Area, Total acres	1.97
BOD removal, percent	80

Table 4 Preaeration Tank Design Criteria

Detention, minutes	30
Volume of air, cfm	100

Table 5 Trickling Filter Design Criteria

Number of Filters	2
Diameter, ft.	39
Media Depth, ft.	22
BOD Loading, lbs./1,000 ft.^{3}	
First Stage	[illegible]1
Second Stage	31
Average	49
Hydraulic loading, gpm/ft.^{2} Surface Area	0.5
Recirculation	None
BOD Removal, percent (includes final clarifiers)	91

Table 6 Final Clarifier Design Criteria

Number of Clarifiers	2
Diameter, ft.	26
Water Depth, ft.	7
Surface Settling Rate, gpd/ft.^{2}	800
Weir Overflow Rate, gpd/ft.	6800

Table 7 Chlorine Contact Basin

Detention, at average daily flow, minutes	49
Max. Chlorine Dosage Capacity, lbs. Cl_2/day	100
Chlorine Dosage Rate, ppm.	10

Table 8 Treatment Plant Pumping Facilities

Trickling Filter Pumps - Variable Speed:	
Filter No. 1:	
Number of Pumps	2
Rated Capacity, gpm.	700
Filter No. 2:	
Number of Pumps	2
Rated Capacity, gpm.	700
Final Clarifier Sludge Pumps:	
Number of Pumps	2
Rated Capacity, gpm.	85

PLANT EVALUATION PROGRAM

Originally, the primary purpose of the evaluation program was to study the performance of the trickling filter system. However, after the program was begun, sampling stations were added so that the dissolved air flotation tank and the anaerobic lagoons could be included in the analysis of the treatment plant performance. The location of all sampling stations is shown in Exhibit 1. Table 9 shows which sampling stations were initially composites and grab samples.

Table 9 Sampling Procedure

Sampling Station	Type of Sampling
S-1, Air Flotation Tank Influent	Composite
S-2, Air Flotation Tank Effluent	Composite
S-3, Anaerobic Lagoon Influent	Composite
S-4, Anaerobic Lagoon Effluent	Grab
S-5, Trickling Filter Effluent	Composite
S-6, Final Clarifier Effluent	Composite
S-7, Chlorine Contact Tank Effluent	Grab
S-8, Final Clarifier Sludge	Composite
S-9, Domestic, Hog Pens, Scald Tank	Composite

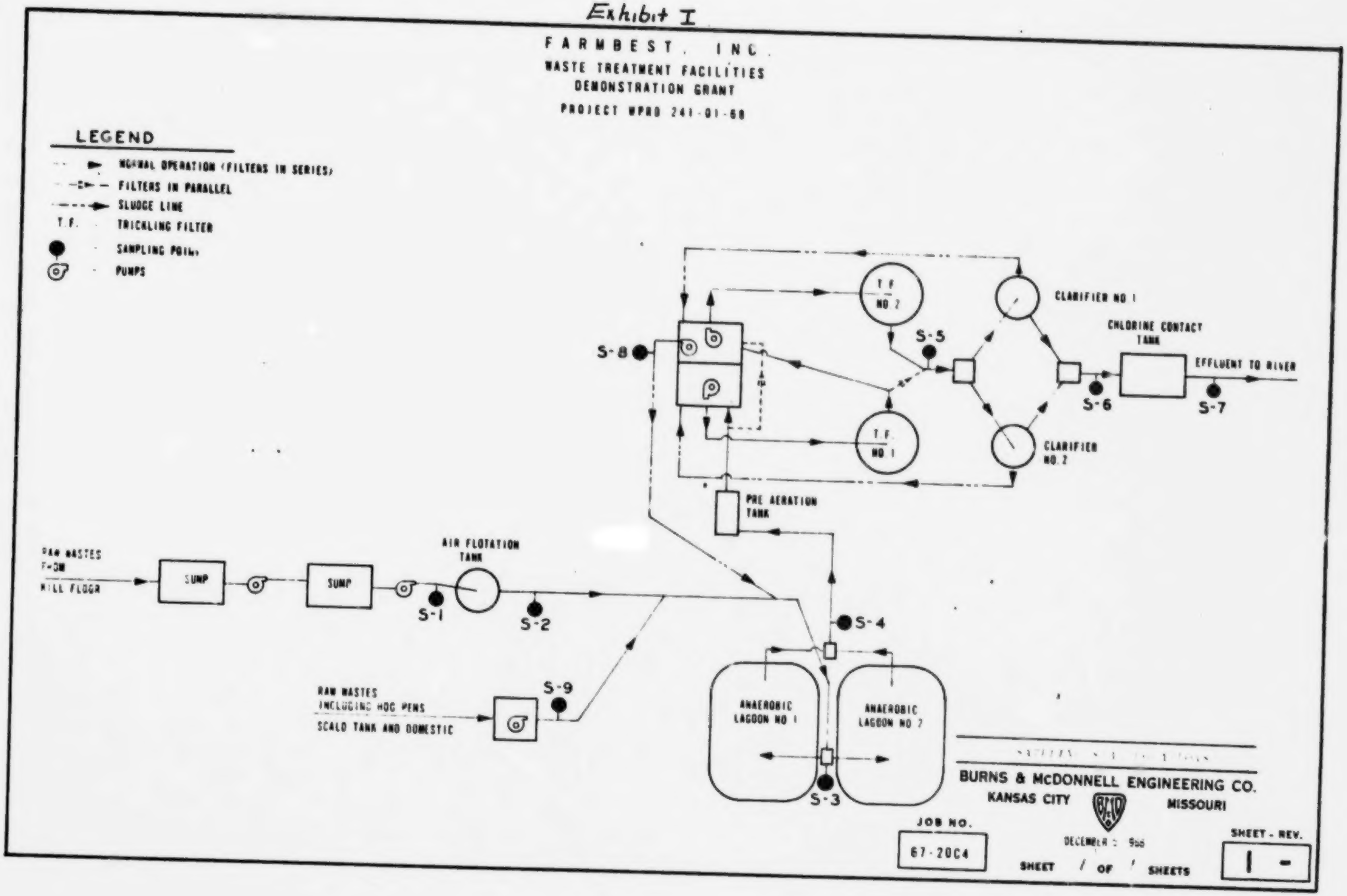
Grab samples were also taken at sampling stations No. S-5 and S-6 to determine if there was any significant difference between a grab sample at these two stations and a composite. The data indicated no significant difference in the results. For this reason, grab samples were taken at S-5 and S-6 in lieu of composite samples.

The final clarifier sludge was sampled by hand several times throughout the pumping cycle. These samples were then mixed together to form a composite.

Three types of automatic samplers were used throughout the program. They included: (1) a suction head type sampler with 24 bottles for compositing, (2) a dip type sampler which dipped a 10-15 ml. sample at a set interval, and (3) a rotating disc type suction sampler.

None of these samplers worked satisfactorily on the air flotation tank influent because of the extremely high grease content which continually caused clogging, and the high moisture content in the atmosphere which shorted out the motors. This problem was eventually solved by providing a siphon off the flotation tank influent line which discharged into a 55 gallon barrel. The sample for analysis was then taken from the barrel after the barrel was properly mixed. All laboratory procedures and analyses were conducted in accordance with Standard Methods, 12th Edition, published jointly by American Public Health Association, American Water Works Association, and the Water Pollution Control Federation.

Exhibit I



FARMBEST, INC.
WASTE TREATMENT FACILITIES
DEMONSTRATION GRANT
PROJECT WPRD 241-01-68

The following analyses were made during the program:

DO
BOD
COD
pH
Alkalinity
Nitrogen Cycle
Complete Solids
Chlorine Residual
Grease
Temperature
Coliforms
Phosphates
Sulfates
Hydrogen Sulfides

In general, all analyses were run at least once per week, and usually two to five times per week.

LABORATORY ANALYSES

Time does not permit the presentation of individual analyses, however, a few of the average analyses appear in Tables 10, 11, 12 and 15.

RESULTS OF EVALUATION PROGRAM

Operational Data

Raw Waste Flows:

The raw waste flows include the wastes from Sewer No. 1 and No. 2. The total flow from these sewers is shown with the maximum and minimum daily flow recorded during each month. The maximum daily flow for the year occurred in December, whereas, the minimum daily flow for the year occurred in June corresponding to the seasonal variation for the industry. The monthly averages throughout the year actually varied very little, with the annual average being 1,123,247 gallons per day.

Trickling Filter Plant Flows:

The trickling filter plant was designed for a constant flowrate. The anaerobic lagoons were to act as holding ponds so that the flow discharged to the trickling filters would be constant seven days a week. The average daily flow discharged to the trickling filters for each month is shown in Table 13, designated as anaerobic lagoon effluent. There is a distinct difference in the flows for the first seven months and the last five months. From January through July, the flowrate to the trickling filters was controlled to buffer the flow over a seven day week. In general, this was done satisfactory, except on some Sundays, where the flow decreased substantially. From August through December, a major operational change was made. It was decided to not have treatment plant personnel present on weekends. Therefore, the anaerobic lagoon was not used as a holding pond, and the major portion of the flow to the treatment facilities were treated as they came in. Thus, only a minor flow was discharged to the treatment facilities during the weekends. Table 14 shows the daily average flow to the filters during these two different operational procedures.

Table 10 **Sulfates and Hydrogen Sulfide, ppm**

Month	Anaerobic Lagoon Effluent		Trickling Filter Effluent		Final Clarifier Effluent		Chlorine Contact Tank Effluent	
	Sulfates	Hydrogen Sulfide	Sulfates	Hydrogen Sulfide	Sulfates	Hydrogen Sulfide	Sulfates	Hydrogen Sulfide
Jan.	40.6	4.4	52.1	0.24	52.1	0	52.6	0
Feb.	34.6	4.3	57.5	0.09	63.7	0	64.9	0
Mar.	40.8	5.0	56.3	0.30	63.3	0	64.8	0
Apr.	32.3	-	82.3	-	73.3	-	55.0	-
May	46.3	-	73.3	-	66.3	-	57.5	-
Average	38.9	4.6	64.3	0.21	63.7	0	58.9	0

Table 11 Chlorides, ppm

Month	Anaerobic Lagoon Effluent	Trickling Filter Effluent	Final Clarifier Effluent	Chlorine Contact Tank Effluent
Jan.	573	528	535	551
Feb.	755	742	737	731
Mar.	803	793	813	779
Apr.	819	816	839	831
Aug.	699	684	684	683
Sept.	735	870	700	860
Average	731	739	718	739

Table 12 7-Day BOD's

June 19, 1970	Raw	4022
	Flotation	1919
	Domestic	1060
	Anaerobic	401
	Filter	564
	Clarifier	195
	Final	53
July 24, 1970	Raw	1309
	Flotation	2944
	Domestic	415
	Anaerobic	294
	Filter (#2)	313
	Clarifier	119
	Final	35
August 19, 1970	Raw	4326
	Flotation	1814
	Domestic	3767
	Anaerobic	526
	Filter	528
	Clarifier	123
	Final	20
September 16, 1970	Raw	11,343
	Flotation	3684
	Domestic	6538
	Anaerobic	458
	Filter	384
	Clarifier	90
	Final	47
October 6, 1970	Raw	5001
	Flotation	2442
	Domestic	3493
	Anaerobic	372
	Filter	298
	Clarifier	88
	Final	31
November 4, 1970	Raw	2663
	Flotation	2086
	Domestic	2498
	Anaerobic	402
	Filter	281
	Clarifier	145
	Final	16
December 16, 1970	Raw	2974
	Flotation	2113
	Domestic	579
	Anaerobic	379
	Filter	362
	Clarifier	87
	Final	121

Table 13 **Plant Flows, GPD**

	Raw Wastes to Anaerobic Lagoon			Final Clarifier Sludge	Anaerobic Lagoon Influent			Anaerobic Lagoon Effluent			Plant Effluent		
Month	High	Low	Average	Return	High	Low	Average	High	Low	Average	High	Low	Average
Feb.	1,223,150	993,720	1,062,893	108,000	1,331,150	1,101,720	1,170,893	940,000	374,000	657,000	832,000	266,000	549,000
Mar.	1,185,780	973,580	1,098,396	108,000	1,293,780	1,081,580	1,206,396	899,000	353,000	652,000	791,000	245,000	544,000
Apr.	1,205,580	951,580	1,065,085	108,000	1,313,580	1,059,580	1,173,085	905,000	396,000	704,000	797,000	288,000	596,000
May	1,258,660	949,640	1,109,410	108,000	1,366,660	1,057,640	1,217,410	1,622,000	243,000	754,000	1,514,000	135,000	646,000
June	1,236,660	866,700	1,099,576	108,000	1,344,660	974,700	1,207,576	1,093,000	824,000	974,000	985,000	716,000	866,000
July	1,160,820	979,820	1,055,530	108,000	1,268,820	1,087,820	1,163,530	--	--	--	--	--	--
Aug.	1,265,800	1,113,680	1,165,440	108,000	1,373,800	1,221,680	1,273,440	1,384,000	638,000	1,127,000	1,276,000	530,000	1,019,000
Sept.	1,232,780	1,145,500	1,173,178	108,000	1,340,780	1,253,500	1,281,178	1,481,000	726,000	1,152,000	1,373,000	618,000	1,044,000
Oct.	1,229,160	1,154,683	1,192,389	108,000	1,337,160	1,262,683	1,300,389	1,334,000	951,000	1,235,000	1,226,000	843,000	1,127,000
Nov.	1,240,800	1,104,183	1,152,119	108,000	1,348,800	1,212,183	1,260,119	1,670,000	740,000	1,170,000	1,562,000	632,000	1,062,000
Dec.	1,277,580	1,069,560	1,181,707	108,000	1,385,580	1,177,560	1,289,707	1,840,000	555,000	1,256,000	1,562,000	447,000	1,148,000
Average			1,123,247				1,231,247			968,000			860,000

Table 14 Trickling Filter Flows

Months	Design Flow*	Actual Average Daily Flow	Percent of Design
Jan.-July	607,000 gpd	748,000 gpd	123%
Aug.-Dec.	607,000 gpd	1,188,000 gpd	195%

*Based on the 5-day working week flow being discharged to the filters over a 7-day week.

Raw Waste Organic Loading:

Initially, sampling of the dissolved air flotation tank influent was not a part of the evaluation program. After the program was begun, it was requested that this waste stream be sampled so that the air flotation tank could be evaluated. Therefore, accurate data of this waste stream and the domestic waste stream (sewer No. 2) is available for only the seven months of the evaluation program.

Table 15 shows the monthly BOD loadings for the two raw waste streams. It is evident that the waste characteristics vary considerably from day to day. Approximately 80 percent of the organic wastes discharge to the dissolved air flotation tank while the remaining 20 percent (from sewer No. 2) discharge directly to the anaerobic lagoons.

Table 15 Raw Wastes, BOD

	Domestic (Interceptor No. 2)				Dissolved Air Flotation Tank Inf. (Interceptor No. 1)				
Month	High ppm	Low ppm	Average ppm	Average lbs	High ppm	Low ppm	Average ppm	Average lbs	Total lbs. BOD
June	1224	369	769	2609	6795	1134	3134	19,260	21,603
July	1449	112	655	2818	2944	943	1771	10,419	13,237
Aug.	3240	411	1260	4489	3720	2484	3178	20,256	25,100
Sept.	5133	317	2058	6949	6336	1407	3515	24,218	31,593
Oct.	3004	378	1402	4841	4301	971	1768	11,336	16,076
Nov.	2197	308	1362	4240	2290	1206	1621	10,186	14,444
Dec.	1052	369	639	2095	7558	1125	3325	21,117	23,212
Average				4006				16,684	20,752

Operational Data Summary:

Table 16 summarizes the basic operational data for the year. The production facilties operated at an average daily kill rate of 3458 hogs per day, approximately 69 percent of maximum production rate. The actual waste flow per hog averaged 186 percent of the anticipated flow, while the BOD per hog averaged 189 percent of the anticipated BOD load during the sampling period. Table 17 compares the design criteria with the actual 1970 operational data.

Table 16 Operational Data

Month	Hogs Killed/day Head	Hogs Killed/day Pounds Live Weight	Gallons of Waste Flow Per Head	Gallons of Waste Flow Per 1000 lbs. Live Weight	BOD Per Head	BOD Per 1000 lbs. Live Weight
Jan. 1970	3,015	692,000	-	-	-	-
Feb. 1970	3,366	765,000	316	1,390	-	-
Mar. 1970	3,216	731,000	342	1,500	-	-
Apr. 1970	3,340	763,000	320	1,400	-	-
May 1970	3,386	784,000	328	1,420	-	-
June 1970	3,382	774,000	328	1,440	6.4	27.9
July 1970	3,031	674,000	348	1,570	4.4	19.6
Aug. 1970	3,519	772,000	331	1,510	7.1	32.4
Sept. 1970	3,876	869,000	302	1,350	8.2	36.4
Oct. 1970	3,743	865,000	321	1,350	4.3	18.6
Nov. 1970	4,241	947,000	283	1,260	3.4	15.2
Dec. 1970	4,149	960,000	285	1,230	5.6	24.2
Average	3,458	800,000	325	1,420	6.0	19.7

/

Table 17 Summary of Raw Wastes

	Design	Average of 1970 Data	Percent of Design
BOD			
lbs./day	21,900	20,752	95%
lbs./hog	4.3	6.0	140%
Waste Flows:			
Gallons per day	850,000	1,123,247	132%
Gallons per hog	175	325	186%

Plant Data

Air Flotation Tank:

This treatment unit is generally considered to be an inplant recovery unit. However, analyses were run on the unit from June through December to determine the performance of the unit.

Since it was extremely difficult to obtain a representative sample of the flotation tank influent, the results are somewhat limited in value. The main constituents removed in the flotation tank are BOD, COD, grease and solids. The annual averages are shown in Table 18.

Table 18 Dissolved Air Flotation Tank Performance

Analysis	Influent, ppm	Effluent, ppm	Percent Removal
BOD	2624	1762	33
COD	4591	4106	11
Grease	1484	559	62
Total Suspended Solids	2223	1507	32

Anaerobic Lagoon:

The anaerobic lagoons performed very well during the test year. The results of the annual averages of the more important parameters are shown in Tables 19 and 20.

The performance of the lagoons were probably enhanced by the thick grease cover which acts as an insulator. The minimum temperature of 60°F. of the lagoon contents occurred in December. The summer temperatures varied between 70-75°F. and the annual average was 69°F.

The lagoons performed as expected, removing an average of 82 percent of the applied BOD even though the lagoons are loaded much heavier than design loading. Based on pounds BOD applied per day, the total organic loading averaged 24,940 pounds BOD per day. Thus the lagoon loading rate averaged 29.3 pounds BOD per 1000 ft.^{3} of lagoon volume. When compared to the design loading rate of 15 pounds BOD per 1000 ft.^{3} of lagoon volume, the lagoons are operating at a loading rate of 195 percent of design.

It is interesting that only 59 percent of the total suspended solids were removed by the anaerobic lagoons. Although the actual lagoon detention during the evaluation program was five days as compared to an expected detention of 7.5 days, based on design hydraulic flows, one would expect a higher removal of suspended solids.

As expected, much of the organic nitrogen was converted to ammonia nitrogen in the lagoons. The pH remained relatively constant during the year, averaging 7.0.

Table 19 Anaerobic Lagoon Performance

Analysis	Influent, ppm	Effluent, ppm	Percent Removal
BOD	2635	477	82
COD	4396	1403	68
Grease	485	106	78
Total Solids	4094	1955	52
Volatile Solids	2112	663	69
Total Suspended Solids	1402	579	59
Organic Nitrogen (N)	95.9	42.1	--
Ammonia Nitrogen (N)	42.5	121.6	--
Sulfates	--	38.9	--
Hydrogen Sulfide	--	4.6	--

Trickling Filters:

The trickling filters were operated in series during the entire program since parallel operation did not provide sufficient hydraulic loading. The performance of the trickling filters are shown in Table 21.

Table 20 Anaerobic Lagoon Influent, BOD

	Domestic + Air Flotation Tank Effluent ppm			Domestic + Air Flotation Tank Effluent lbs.			Final Clarifier Sludge Return	Anaerobic Lagoon Influent, lbs.		
Month	High	Low	Average	High	Low	Average	lbs.	High	Low	Average
Feb., 70	5960	3836	4868	49,394	31,791	40,346	770	50,164	32,561	41,116
Mar., 70	3406	1648	2392	29,007	13,381	21,123	770	29,773	14,151	21,893
Apr., 70	5265	2760	3340	45,962	21,903	33,464	770	46,732	22,673	34,234
May, 70	4645	2986	3830	39,760	25,560	36,053	770	40,530	26,330	36,823
June, 70	2780	1295	2102	25,751	13,356	19,930	770	26,521	14,126	20,700
July, 70	2130	1260	1672	19,049	12,198	14,978	770	19,549	12,968	15,748
Aug., 70	3521	1370	2176	37,170	12,725	21,985	770	37,940	13,495	22,755
Sept., 70	4149	1013	2440	39,905	10,415	23,599	770	40,675	11,185	24,369
Oct., 70	2265	818	1453	22,087	7,977	14,103	770	22,857	8,747	10,873
Nov., 70	2520	2251	2386	26,078	22,094	24,086	770	26,848	22,864	24,850
Dec., 70	2041	1421	1731	18,206	14,197	16,201	770	18,976	14,967	16,971
Average			2635			24,169				24,939

Table 21 Trickling Filter Performance

Analysis	Trickling Filter Influent, ppm	Trickling Filter Effluent, ppm	Final Clarifier Effluent, ppm	Total Percent Removal
Dissolved Oxygen	0	2.3	3.9	---
BOD	477	296	124	74
COD	1403	1010	372	73
Grease	106	73	33	69
Volatile Solids	663	706	354	47
Volatile Suspended Solids	418	443	83	80
Total Suspended Solids	579	602	108	80
Organic Nitrogen (N)	42.1	41.1	21.3	49
Ammonia Nitrogen (N)	121.6	103.2	100.0	18
Nitrate Nitrogen (N)	9.3	25.2	15.1	--
Sulfates	38.9	64.3	63.7	--
Hydrogen Sulfide	4.6	0.2	0	100
Total Phosphates	53	52	53	0

The efficiency of the trickling filter system was not as good as anticipated. It was hoped that the trickling filters would remove approximately 90 percent of the applied organic loading. However, the design organic loading was 2580 pounds BOD per day, whereas, the actual organic loading was 3850 pounds BOD per day during the test year, or 150 percent of design loading. This results in an overall loading rate of 73.4 pounds of BOD per 1000 cubic ft. of filter media. The hydraulic loading rate during the evaluation program averaged 0.79 gpm per ft.^{2} of surface area. The design hydraulic loading rate was 0.5 gpm per ft.^{2} of surface area, or 158% overloaded.

The filter provided ample aeration to the wastes, with the dissolved oxygen in the filter effluent averaging 3.9 ppm.

The filters removed 100 percent of the hydrogen sulfide present, but did not remove any phosphates, with approximately 53 ppm being discharged in the final clarifier effluent. The filters and clarifiers provided good grease removal, but still discharged an effluent with an average of 33 ppm grease.

Several solids analyses were run on the final clarifier sludge. These analyses are shown in Table 22. It was hopeful that some

Table 22 Trickling Filter Sludge Solids Analyses, ppm

Date	Total Solids	Fixed Solids	Volatile Solids	Suspended Solids			Dissolved Solids		
				Total	Fixed	Volatile	Total	Fixed	Volatile
7/17/70	6696	2418	4278	5422	1358	4064	1274	1061	213
8/11/70	2659	1769	890	1424	792	632	1236	977	259
9/10/70	10,439	2375	8064	9183	1388	7795	1256	987	269
1/24/70	6284	2365	3919	4988	1289	3699	1296	1075	221
1/26/70	6762	2486	4276	5472	1428	4044	1290	1058	232
1/27/70	6950	2542	4408	5633	1463	4170	1317	1079	238
Average	6632	2326	4306	5354	1286	4067	1278	1039	239

correlation could be obtained between the applied BOD and solids produced. However, in comparing the suspended solids in the filter influent with the suspended solids in the final clarifier effluent and sludge, little correlation can be made. Table 23 shows the pounds of suspended solids per day in the various waste streams. It is evident from Table 23 that the average suspended solids loading discharged to the filters was 5340 pounds per day, whereas, the total pounds of suspended solids removed as sludge and discharged in the clarifier effluent averaged 5577 pounds per day, for a net gain in suspended solids of 237 pounds per day.

Table 23 Suspended Solids, Lbs. Per Day

Month	Trickling Filter Influent	Final Clarifier Effluent	Final Clarifier Sludge
January	--	--	
February	2120	473	
March	3527	473	
April	3527	512	
May	2442	813	
June	3430	457	
July	2948	663	
August	6193	558	
September	8204	886	
October	8650	904	
November	6404	1350	
December	13,487	1355	
Average	5340	767	4810

Chlorine Contact Basin:

The chlorine contact basin was designed for disinfection of the final effluent, however, the analyses show that some BOD and suspended solids were also removed in the chlorine contact basin. Table 24 shows the performance of the chlorine contact basin.

Table 24 Chlorine Contact Basin Performance

Analysis	Basin Influent, ppm*	Basin Effluent, ppm*	Percent Removal
BOD	124	61	51
COD	372	371	0
Grease	33	17	49
Volatile Solids	354	348	2
Volatile Suspended Solids	83	68	18
Total Suspended Solids	108	90	17
Chlorine, Total	7.7	1.3	--
Coliforms (per 100 ml)	35,300,000	1513	99.99

*Except Coliforms

In studying the BOD analyses of the chlorine contact basin's influent and effluent, it may be that the chlorine affected the BOD test of the final effluent. Even though the proper procedure for dechlorination was followed in accordance with Standard Methods, 7.7 ppm of chlorine can not oxidize 63 ppm of BOD.

Table 25 gives the monthly chlorine usage and coliform destruction through the chlorine contact basin. Excellent disinfection was accomplished during the year. It is evident from the data that the majority of the available chlorine was immediately tied up as combined chlorine. This would certainly be expected with such high ammonia nitrogen concentrations in the waste stream.

Summary of Treatment Plant Performance:

Table 26 summarizes the average efficiency of each plant unit.

Table 26 Plant Efficiency Percent Removal

Analysis	BOD	COD	Grease	Suspended Solids	Coliform
Dissolved Air Flotation Tank	33	11	62	32	---
Anaerobic Lagoon	82	68	78	59	---
Trickling Filters	74	73	69	80	---
Chlorine Contact Tank	51	0	49	17	99.99
Total Plant Removal, Excluding Dissolved Air Flotation Tank	97.4	91.5	96.5	93.5	99.99

Table 25 Chlorine Usage and Coliform Reduction

Month	Chlorine Contact Tank Influent		Chlorine Contact Tank Effluent			Coliforms/100 ml	
	Chlorine lbs./day	Chlorine ppm	Free Chlorine ppm	Combined Chlorine ppm	Total Chlorine ppm	Chlorine Contact Tank Influent	Chlorine Contact Tank Effluent
January	50	---	0.7	3.2	3.9	22,200,000	65
February	50	9.1	0.5	0.8	1.3	24,000,000	125
March	44	8.0	0.4	0.2	0.6	17,700,000	836
April	50	8.5	0.1	0.3	0.4	35,200,000	4500
May	50	7.9	0.3	0.6	0.9	12,300,000	767
June	60	7.3	0.1	0.9	1.0	21,200,000	1360
July	50	---	0.1	0.8	0.9	---	---
August	70	7.5	0.1	0.7	0.8	---	---
September	60	6.3	0.1	0.7	0.8	---	---
October	90	8.7	0.2	0.7	0.9	---	---
November	70	7.2	0.1	2.7	2.8	---	---
December	70	6.7	---	---	---	---	---
Average	60	7.7	0.2	1.1	1.3	35,300,000	1513

OPERATING EXPENSES

Operating expenses were recorded for all treatment units with the exception of the dissolved air flotation tank. Since the primary purpose of the flotation tank is to recover a saleable product, grease, it is considered to be an inplant recovery unit, and not a treatment unit. Operating expenses include personnel salaries, utilities, chemicals, repairs, and debt service. Table 27 summarizes the annual operating expenses for 1970.

Table 27 Annual Operating Expenses, 1970

Salaries	$ 47,893
Utilities	1,443
Maintenance & Operating	10,412
Subtotal	$ 59,748
Debt Service	$ 50,900
Total	$110,648

The daily operating expense was $304. per day. Table 28 shows the total operating expenses based on different parameters.

Table 28 Operating Expenses, 1970

Per Hog Killed	$0.09
Per 1000 lbs. Live Wt.	$0.39
Per lb. BOD in Raw Wastes	$ .014
Per 1000 Gallons of Raw Wastes	$0.28

During the latter part of 1970, Farmbest reduced their personnel at the treatment facilities. This will significantly reduce their annual operating expenses, but should not affect the plant operation. Table 29 shows the projected operating expenses for 1971.

Table 29 Estimated Annual Operating Expenses, 1971

Salaries	$10,500
Utilities	1,500
Maintenance	300
Operating	8,100
Subtotal	$20,400
Debt Service	$50,900
Total	$71,300

Table 30 shows what the estimated expenses will be for 1971 based on the same parameters as shown in Table 28. These figures are based on the assumption that the kill rate, waste flow, and organic concentration of the waste stream will be similar to the 1970 averages.

Table 30 Estimated Operating Expenses, 1971

Per Hog Killed	$0.06
Per 1000 lbs. Live Wt.	$0.24
Per lb. BOD in Raw Wastes	$.009
Per 1000 gallons of Raw Wastes	$0.17

CONCLUSIONS

The primary purpose of this research and demonstration project was to determine the performance of an anaerobic lagoon system followed by plastic media trickling filters for treating meat packing wastes. At the time this project was constructed, the treatment of an anaerobic lagoon effluent by plastic media trickling filters was untried.

The anaerobic lagoons operated as expected, removing 82 percent of the applied BOD even though the applied loading averaged 195 percent of the anticipated loading rate. The lagoons are an excellent treatment unit for treating packinghouse wastes. High removal rates of organic materials at a minimum capital and operating expenses are accomplished with anaerobic lagoons.

The trickling filter system did not perform as hoped for; however, there are several reasons why the trickling filter system cannot perform at its highest efficiency. Since the final clarifiers are an integral part of the trickling filter system, the filters and clarifiers must be analyzed together in determining the performance of the trickling filter system.

The data clearly shows that the trickling filters organic loading is 150 percent of design loading and the hydraulic loading is 158 percent of design loading. The higher organic loading will decrease the efficiency of the system. It is doubtful that the increase in hydraulic loading would affect the trickling filter operation. However, the detention time in the final clarifiers is reduced significantly. The clarifiers were designed to provide a detention time of 2.3 hours, based on an average flow rate of approximately 607,000 gpd during a seven day week. However, the anaerobic lagoons are not being utilized as a holding pond as originally anticipated. Therefore, the majority of the weekly flow is discharged to the treatment facility the normal five day work week. This fact, coupled with higher hydraulic flow, which averaged 968,000 gpd being discharged through the trickling filter system for 1970, reduces the detention time to approximately 1.4 hours.

During the last five months of 1970, the flow discharged to the trickling filters averaged 1,188,000 gpd. The detention time during this period was further reduced to 1.2 hours. It is obvious that the final clarifiers cannot operate as an efficient unit under such hydraulic loads.

The suspended solids concentration in the final clarifier effluent averaged 108 ppm during the evaluation program. Further reduction of suspended solids and BOD within the clarifiers would be extremely difficult to obtain at such high hydraulic loading rates unless chemical coagulation facilities are added ahead of the clarifiers.

Another factor which may be affecting the settling characteristics of the solids is the grease concentration in the trickling filter effluent. The filter effluent averaged 73 ppm of grease. It may be that the grease tended to adhere to the solids and change their specific gravity. This would create a light sludge with poor sludge settling characteristics. Flotation of solids and grease is apparent in the basins. Although skimming is provided on the final clarifiers considerable solids are being discharged in the effluent.

Another possible cause of poor solids settling characteristics is that denitrification is occurring in the basins. Although the nitrate data is limited and quite variable, the trend indicates that denitrification is occurring.

Based on the above discussion, it is apparent that the extremely high organic and hydraulic loading rates above what was anticipated has contributed to the reduction in expected plant efficiency. The anaerobic lagoon and trickling filters operated very well under these extreme conditions. However, the data indicates that the final clarifiers were greatly affected by the high hydraulic loading rates and by some constituents in the waste stream.

DEHYDRATION OF CATTLE RUMEN AND WHOLE BLOOD

by

Dr. Donald J. Baumann*

The following is a progress report of a current project in effect at Beefland International, Inc., at Council Bluffs, Iowa, which is partially supported by the Environmental Protection Agency.

The title of this industrial waste project is: "Elimination of Water Pollution by Packing House Animal Paunch and Blood." The eighteen-month project known as EPA Project No. 12060-FDS was approved in October 1969, and runs until April 1971.

Objectives of the Project

Although the general objective of this demonstration project is the elimination of potential water pollutants of animal paunch (rumen) and blood, the specific objectives are to determine the total quantity of rumen and blood that is generated in this beef slaughtering operation, and the determination of the total biochemical oxygen demand (BOD) and the total chemical oxygen demand (COD) of these materials expressed in the proper units. In addition, the cost of the dehydrating process of the animal whole blood and the rumen in terms of gas and electricity consumption is to be established. Chemical analyses of the dehydrated products are carried out because of the actual and potential use of these materials as legal feeds or feed additives.

Beefland International, Inc.

Construction of the physical plant of Beefland International, Inc., was begun in 1968 and was completed in 1969. Kill operation was begun at the plant in January 1970. It will have, at full production, the largest kill-capacity of any slaughtering operation ever approved by the U. S. Department of Agriculture. At its maximum kill-capacity of 250 head per hour, a potential kill of 2,500 cattle will be processed daily. At this rate, a waste problem of approximately 250,000 pounds of rumen and blood alone would arise daily.

To solve this problem, Beefland installed one McGehee paunch dehydrator and one McGehee blood dehydrator in a building adjacent to the beef-slaughtering plant. Paunch and blood obtained in the slaughtering process are fed through a series of holding tanks to these dehydrators.

---

*Professor of Chemistry at Creighton University, Omaha, Nebraska, and Technical Director of EPA Project, 12060-FDS, Beefland International, Inc.

Blood, Rumen, and Waste Water Flow

The blood of the animals flows through several openings on the kill floor directly to a holding tank below from whence it is periodically blown over into holding tanks adjacent to the blood dehydrator. Similarly, the rumen from each paunch is emptied into a hopper on the kill floor into a holding tank below. From that tank it is likewise blown over periodically by means of air and steam pressure along an overhead line to a second holding tank adjacent to the paunch dehydrator in the separate dehydrator building. Figure 1 is a schematic diagram which shows this flow of blood and rumen.

The waste water which originates from the washing of animal carcasses and parts, as well as that which arises from the periodic hosing down of sections of the kill floor during and at the completion of operations of the day, flows into a central sump. The waste water from the hosing down operation of the outside holding pens is similarly collected in this central sump. It is pumped from the sump into a Sedifloater-Clarifier plant.

The Sedifloater-Clarifier plant is composed of two sections--a flotation unit and a pressurizing system. The flotation unit is comprised of an open-top steel tank, 50 feet in diameter, and various internals specifically designed to handle the grease "float," the settled solids, and the clarified liquid. The pressurizing unit consists of special pumps, an air injection system, an air saturation tank, and an air-release system with required piping.

The air-saturated waste liquid flows under pressure to the flotation unit. Just before it enters the flotation unit, it passes through a pressure release valve. This sudden reduction in pressure as the waste liquid passes through the valve causes the air to come rapidly out of solution in the form of tiny bubbles. These bubbles attach themselves to suspended particles in the liquid causing them to rise in the Sedifloater-Clarifier. The fatty "float" thus formed is then removed into a discharge outlet. Floor scrapers in the flotation unit move the settled particles to a sludge pump from which they are removed for ultimate disposal. The clarified liquid is drawn out of the flotation unit from a level below mid-depth and discharged into an aeration basin or lagoon. The lagoon has the dimensions of 150 ft x 450 ft with a waste water depth of approximately 10 ft. There, four 50-horsepower electric surface aerators tranfer oxygen into the effluent piped from the Sedifloater-Clarifier, thereby further reducing its impurity content by aerobic oxidation. Finally, the now clarified effluent is discharged from the aeration basin into the city's sewage system. Figure 2 shows the waste-water flow and component systems described above.

Dehydrators and the Dehydrator Building

The building housing the dehydrators is a simple structure with corrugated metal sheets covering a metal framework. The building is approximately 40 ft wide, 80 ft long, and 40 ft high.

BLOOD AND PAUNCH FLOW

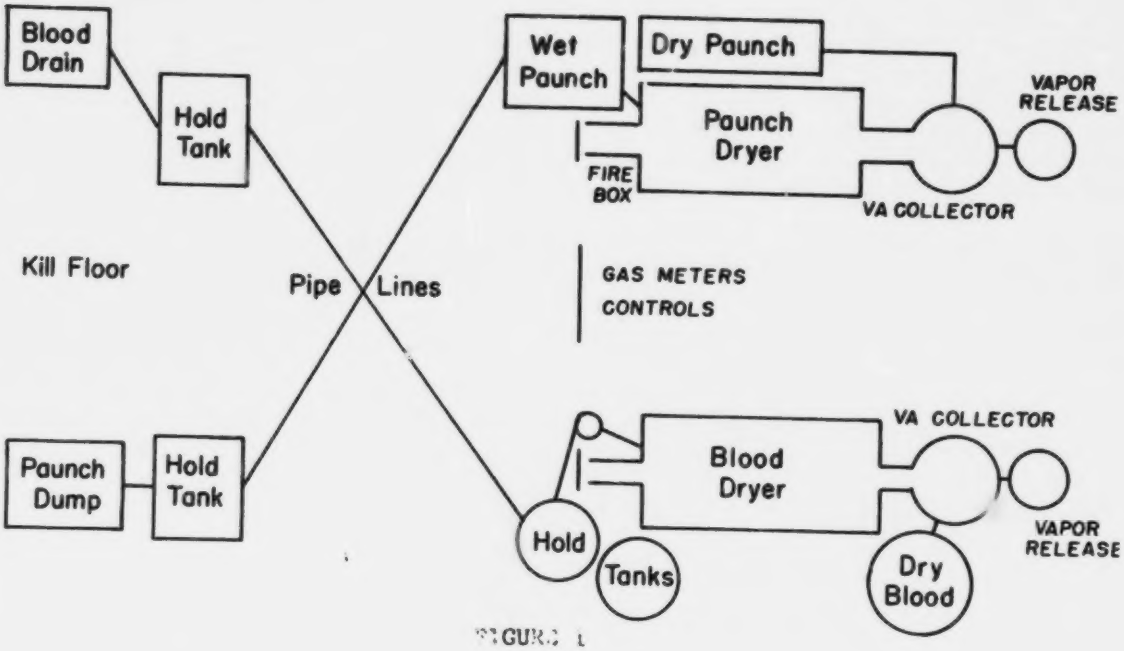


FIGURE 1

WASTE WATER FLOW

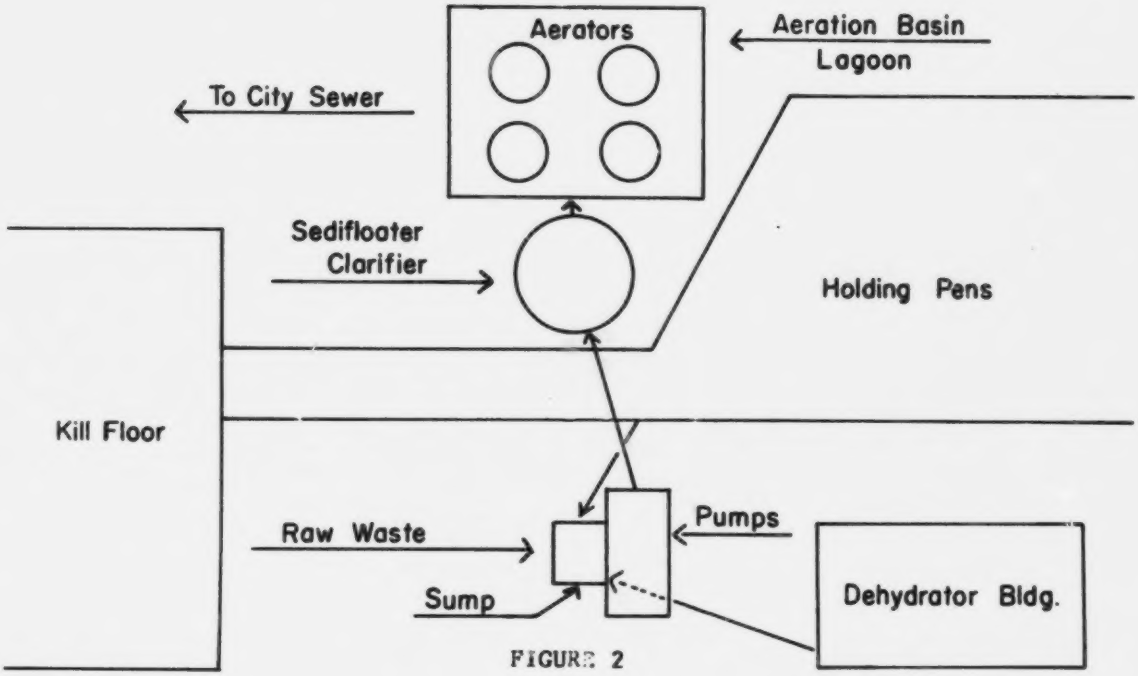


FIGURE 2

Each of the McGehee dehydrator units has a diameter of 8 ft with a length of 20 ft. These drums revolve on four sets of ordinary rubber tires (three tires per set) which are motor driven and located at the four corners of each drum. A ten-foot-long air-cooled firebox is located at the front of each drum. An adjustable sleeve located on the opposite end of the drum aids in the control of the moisture content of the product. Each dehydrator unit is equipped with a vacollector and gas release system. Figure 1 shows the arrangement of these components, as well as the storage facilities for both the fresh rumen and blood and the dehydrated products.

The gas-fired dehydrators are operated at different temperature ranges. The dehydration of the rumen has been carried out in the range of 180°F to 230°F. The blood has been dried between 130°F to 180°F. Temperature readings are taken at the point where the dried products enter the vacollectors.

The first of the dehydrators (for whole blood) was put into operation about mid-March 1970. The second unit for the dehydration of rumen became operational by May 1, 1970. Table 1 summarizes the cost of the dehydrators and building construction.

Table 1. Dehydrator Building Costs

Blood Dehydrator	$ 52,000
Paunch Dehydrator	62,000
Construction Costs	24,700
Total	$138,700

The Laboratory

When approval of the demonstration grant by EPA officials to Beefland International, Inc., was received in late 1969, plans for the laboratory facilities needed to reach the outlined objectives of the project were begun.

Several suitable sites for the laboratory within the main plant building were selected. The company administrators elected, however, to house the laboratory outside the main building within a reasonable distance of all sampling sites. Although it was recommended that a minimum of 12 ft x 20 ft floor space be provided for adequate floor and counter-top space for the required equipment, a considerably smaller space for the laboratory finally evolved.

A Behlen corrugated metal flat-topped building was erected on a concrete slab behind the main plant buildings. The inside dimensions are approximately 10 ft x 17 ft with an 8 ft dropped ceiling. Of the 170.8 sq ft floor plan, an area of 47.4 sq ft is taken up as counter space. The building was erected during the month of April, 1970.

Occupancy and use of the completed laboratory facility was not possible until November 1, 1970. This was due to the unexplained delay in the delivery and installation of the laboratory cabinetry, counter-tops, and fume hoods by the vendor. Analytical work on dehydrated rumen and blood was begun by April first by the chemist employed by Beefland International. As a M.S. graduate student at Creighton University, he carried on the analytical work at the university. He continued utilization of these facilities until the Beefland laboratory was completed.

The total expenditures for the laboratory facilities were $12,300, of which $4,400 were expended for the construction of the buildings. The major equipment items ($100 or more/unit) purchased are listed in Table 2.

Table 2. Major Laboratory Equipment

Automatic Read-out Balance
BOD Incubation Cabinet
Distillation Apparatus and Redistillation Kit
Drying Oven
Extraction Heater--6 Unit
Kjeldahl Combination Digestion and Distillation Apparatus--6 Unit
Pulverizer--Hammer Type
pH Meter
Muffle Furnace
Spectronic-20 Colorimeter
Electric Grinding Mill

Analytical Data

Analysis of the dehydrated products began immediately after the dehydrators became operational. The percent moisture of both the dehydrated rumen and blood ranged between wide limits during the first months of operation because of the inexperience of the operators and adjustments required on the dryers. The last sixty determinations of the various analyses made are given in Table 3. The methods used in the analytical procedures are those from "Official Methods of Analysis of the Association of Official Agricultural Chemists," 10th Edition, 1965.

Table 3. Analysis of Dehydrated Products[1]

		Mean-%	Std. Dev.
Blood			
	Moisture	5.4	1.9
	Protein	88.0	4.7
Rumen			
	Moisture	7.1	2.0
	Protein	12.2	1.4
	Fat	3.2	0.4
	Crude Fiber	26.1	3.6
	Calcium	0.59	0.09
	Ash	7.1	0.71
	P_2O_5	1.47	0.25
	Carbohydrate[2]	39.2	5.5

---

[1] A total of 30 samples but 60 separate determinations.

[2] The % carbohydrate calculated by subtracting total percentage of moisture, protein, fat, crude fiber, and ash from 100% for each sample as advised by Mr. Whitson of the Iowa Agricultural Laboratory in Des Moines, Iowa.

Data on undehydrated blood is summarized in Table 4. The chemical oxygen demand (COD) determination is that given for high level demand industrial waste in "Standard Methods for Examination of Water and Wastewater," 12th Edition, 1965, and in "FWPCA Methods for Chemical Analysis of Water and Wastes," November 1969. No correction for chloride ion was made in the calculation of total COD. The biochemical oxygen demand (BOD) procedure used is the modified Azide-Iodide Winkler method for dissolved oxygen.

Lagoon water was found to be the best seed in the BOD determination of the fresh blood. The seed correction, taking the dilution factor into account, was made on those BOD measurements of seed alone which gave a 40 to 60 percent depletion of dissolved oxygen.

Table 4. Data on Fresh Blood

	Mean	Std. Dev.	No. of Detm's[1]
pH	7.40	0.12	26
% Moisture	83.4	3.3	28
COD (ppm)	206,070	30,910	48
BOD_5 (ppm)	132,440	47,340	24
BOD_5 of Lagoon Water[2] (ppm)	139	60	42

[1] The same as number of samples for pH and % moisture. Two determinations per sample made on COD and BOD.

[2] Lagoon water (plant effluent) used as the seed in BOD determination of undehydrated blood.

Table 5 summarizes the data acquired to date on undehydrated rumen. The COD and BOD are established separately for the liquid and solid portions of the material. The sample taken for each analysis is filtered, washed repeatedly and the washings diluted to 2,000 ml. The solid portion remaining on the filter is dried overnight in a 105°Foven, thus giving the composition of the sample.

It was ascertained that use of a seed was required for the BOD determination of the liquid portion of the rumen. Holding pen droppings with a little fresh paunch added but filtered before use was found to act as an excellent seed in this determination. With the advent of very cold weather, the BOD determination results of the liquid portion of the paunch became erratic. The BOD determination of the dried solid portion of the rumen has presented some technical problems which have not been solved to date.

Table 5. Data on Undehydrated Rumen

	Mean	Std. Dev.	No. of Detm's[1]
pH (liquid + wash.)	6.60	0.69	23
% Moisture	86.3	2.9	24
COD (ppm)			46
Liquid Portion	53,820	9,860	
% Liquid	(90.4)	(3.0)	
Solid Portion	1,179,870	87.320	
% Solid	(9.6)	(3.0)	
Total COD	161,350	34,710	
% COD from Liquid	30.9	6.3	
% COD from Solid	69.1	6.3	
BOD_5 (ppm)			28
Liquid Portion	21,730		
Solid Portion	no data		

---

[1] The number of determinations is the same as number of samples for pH and % moisture, but two times the number of samples for COD and BOD.

Table 6 summarizes the kind of information which is being reported monthly concerning the operation of the dehydrators. Correlations will be able to be made at the end of the project period which will give the expected yields of dehydrated products on the basis of the daily kill. Costs for labor, gas, and electricity per unit-weight of dehydrated product will also be known.

Table 6. Production and Cost Data--January, 1971

Head of Cattle Slaughtered	32,582
Days of Operation	24
Blood Dehydrator	
Pounds of Dried Blood Produced[1]	195,492 lbs
Drying Time Required	224½ hrs
Gas Consumption	1,560.71 MCF
Electricity Consumption	9,216 KWH
Man-hours Required	337½ hrs
Paunch Dehydrator	
Pounds of Rumen Generated[2]	1,824,592 lbs
Pounds of Dried Rumen Produced[3]	158,438 lbs
Drying Time Required	208¾ hrs
Gas Consumption	1,266.8 MCF
Electricity Consumption	23,040 KWH
Man-hours Required	342¼ hrs
Total Gas Costs (both dehydrators)	$1,387.02
Total Electricity Costs (both dehydrators)	$379.01

---

[1] Based on estimated 6 lbs/animal.

[2] Calculated on basis of 56 lbs/animal.

[3] Contents of 22,634 paunch dried (69.5% of total). Weight based on 7 lbs dried rumen/animal.

Slides of all tabular data contained in this report were shown during the presentation. In addition, about 60 colored slides of photos taken both outside and inside of the main plant, dehydrator building, and the laboratory were shown to more clearly represent the details of the project as described.

To date, only 40 to 70 percent of the total rumen generated has been dehydrated each month. A better market for this product must be created. Plans are currently being studied for the installation of a pelletizing machine for the dried rumen which would incorporate the recovered fat from the Sedifloater-Clarifier in the product.

WATER AND WASTE MANAGEMENT IN POULTRY PROCESSING

by

Dr. W. M. Crosswhite, R. E. Carawan and John A. Macon*

The research, development and demonstration project in water and waste management in poultry processing is being conducted at the Gold Kist plant in Durham, North Carolina. The purpose of the project is to make changes in plant equipment and operations throughout the plant. Specific objectives are to:

1. Install and/or modify process equipment and demonstrate its operations for water and waste reduction.

2. Evaluate the impact of production methods, technical changes in equipment, conditioning of water and by-product development on water use and reuse and pollution abatement.

3. Determine the economic implications for the several water and waste reduction methods demonstrated in the project.

4. Formulate guides for the management of water and waterborne waste in poultry processing.

Technical and research requirements in support of the project have been provided by North Carolina State University. The University has responsibility for:

1. Training key personnel to carry out measurement and control work within the plant.

2. Supervising the sampling and testing of all process waste water to determine both quantities and pollutional characteristics.

3. Providing guidance and coordination in the development and fabrication of specialized equipment.

4. Coordinating technical changes in plant processes and installation of equipment with plant management.

5. Providing systems evaluation and benefit-cost analyses for the several economic alternatives demonstrated in the project.

---

*Respectively, Associate Professor, Department of Economics; Extension Specialist, Department of Food Science; and Research Associate, Department of Economics, North Carolina State University, Raleigh, N. C.

6. Publishing results and related information developed in all phases of the project including recommendations and guides for the management of water and waste in poultry processing.

SPECIAL FEATURES

This project has a number of features which are of special interest.

1. The project was jointly developed and conducted by a federal agency, Environmental Protection Agency; by industry, Gold Kist; and by an educational institution, North Carolina State University.

2. An interdisciplinary research team has worked cooperatively. Members have had training in microbiology, food science, engineering and economics.

3. The project encompasses both water use and waste abatement throughout the plant, from water intake through final waste water collection and control. Systems analysis has been applied.

4. There has been a full-time staff in the plant working on the project without assigned production-related responsibilities.

5. The University has provided supporting biological evaluation in all phases of the project.

6. A cooperative working relationship with the product inspection staff has been achieved which has enhanced the effectiveness of the project.

PLAN-OF-WORK

The plan-of-work was organized into three phases: collecting benchmark information (6 months), technical development (12 months) and evaluation, formulation of management guides and preparation of the final report (6 months). A water and waste laboratory was set up in the plant for use in preliminary studies and laboratory analysis.

Benchmark Information

Benchmark information was obtained on water and waste quantities, waste water characteristics and biological characteristics of both the product and water at selected points throughout the plant. A flow chart was developed for identifying processes, water sources, sampling points, by-product recovery points, product flows and waste water flows, Figure 1.

Processing waste water characteristics for the feather flume, eviscerating flume, selected processes and total effluent are given in Table 1. Water used in the plant is given in Table 2.

Technical Development Activities

Water has many uses in poultry processing including scalding, product preparation, cooling the whole birds and parts, transporting wastes and

FLOW CHART OF POULTRY PROCESSING PLANT

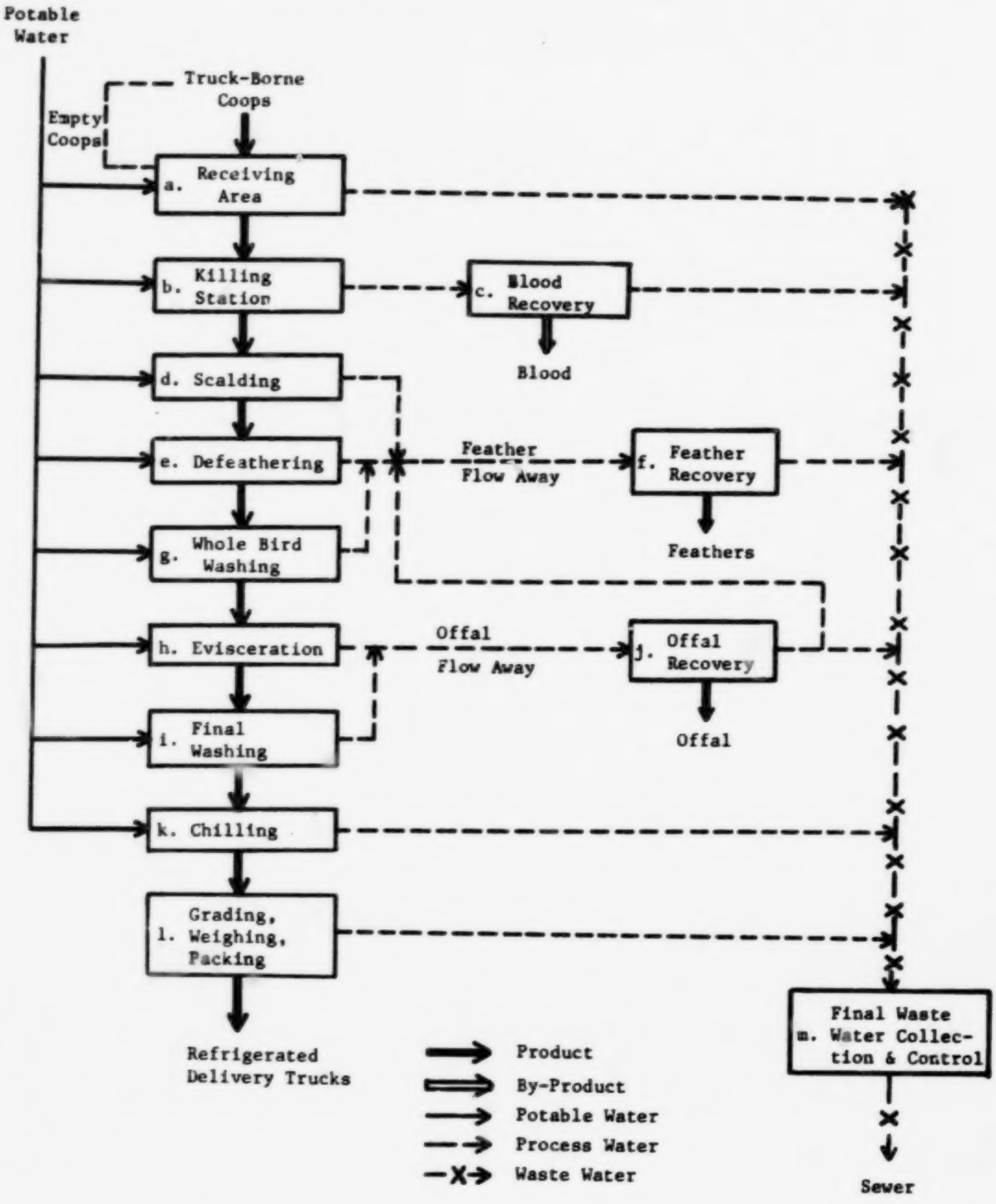


Figure 1. Flow Chart of Poultry Processing Plant

Table 1. Benchmark data on water and waste, Gold Kist Plant, Durham, N. C., December, 1969

	BOD	COD	Solids			Grease
			Total	Dissolved	Suspended	
1. Scalder Entry	1,182	2,080	1,873	1,186	687	350
2. Scalder Exit	490	986	1,053	580	473	200
3. Whole Bird Wash	108	243	266	185	81	150
4. Final Bird Wash	442	662	667	386	281	580
5. Giblet Chiller	2,357	3,959	2,875	1,899	976	1,320
6. Chiller I	442	692	776	523	253	800
7. Chiller II	320	435	514	331	183	250
8. Feather Flume	590	1,078	894	382	512	120
9. Eviscerating Flume	233	514	534	232	302	430
10. Plant Effluent	560	722	697	322	375	150

Table 2. Measured water use for poultry processing, Gold Kist Poultry Processing Plant, Durham, N. C., July, 1969

Process	Source	Flow Rate (gpm)	Total Volume (gal)
1. Killing Station		2.0	1,080
2. Scalder	Fresh	38.7	20,898
3. Pickers	Fresh	38.0	20,520
4. Feather Flume	Fresh Chiller Effluent Re. Offal Water	94.3 54.6 111.7	50,922 — --
5. Neck Scalders	Fresh	1.5	810
6. Whole Bird Washers	Fresh	37.3	20,142
7. Defeather Cleanup Hose (1 @ 1 hr.)	Fresh	34.0	2,040
8. "Hang-Back" Belt	Fresh	9.1	5,460
9. Eviscerating Trough			
a. Hand Wash Outlets	Fresh	285.0	153,900
b. Side Pan Wash	Fresh	90.0	48,600
10. Final Bird Wash	Fresh	100.0	54,000
11. Lung Vacuum Pump Effl.	Fresh	14.2	7,668
12. Gizzard Machine & Giblet Flumes	Fresh	360.0	194,400
13. Evisc. Cleanup Hose (2 @ 30 min. ea.)	Fresh	72.0	2,040
14. Giblet Chiller	Fresh & Ice	4.5	2,430
15. Neck Cutter	Fresh	4.0	2,160
16. Chillers	Fresh & Ice	72.1	38,934
17. Packing Ice	Ice	15 lbs/box	6,111
18. Bird Pickup (10% in chillers)	Fresh	--	8,640
19. Packing Cleanup Hoses (3 @ 10 min. ea.)	Fresh	102.0	1,020
20. By-Product Cleanup Hoses (1 @ 10 min.)	Fresh	34.0	340

Normal processing day runs from 7:00 a.m. - 4:00 p.m. 725,600 (1,340) gpm

Water Meter Readings: a. Processing (7:00 a.m. - 4:00 p.m.) = 725,600 gpd
b. Cleanup (4:00 p.m. - 7:00 a.m.) = 112,200 gpd
Total = 837,800 gpd

Undetermined Process Water: 850,000 - 837,800 = 12,200 gpd

Note: Cleanup hoses are used to rinse off equipment at break periods and lunch during processing operation.

cleanup. Waste added to the water in these processes generates high-strength waste waters when compared to normal municipal waste waters. Most of these wastes are highly degradable by biological and chemical waste treatment processes.

Relatively low water and sewer costs and the absence of restrictions and surcharges on waste loadings have resulted in a low priority on research and development of information. There is little information on in-plant water and waste reduction methods. More importantly, traditional production techniques are often not compatible with economic water and waste management solutions.

Water reduction developments are outlined in Table 3 for the several major processes in the poultry plant. Each section of the plant is separated by walls with the activities well defined in each area in the regulations.

Further water reductions could be achieved by continued use of process waters, studies of which are now under way. These two changes would involve the use of the whole bird wash water in the scalder and the use of chiller and final bird wash water in the gizzard splitting machine. The potential savings are 120 gallons per minute.

The application of waste reduction methods has been much more limited than water reduction methods. An improved blood recovery system using troughs with high sides has been installed to contain the blood in the killing area. The blood is shipped to the by-product processing plant in a tank installed under the bed of the feather and offal truck. This change has reduced cleanup requirements of labor and water and is expected to provide for almost complete recovery of blood from the killing area. Stunners are used to reduce body action and the amount of blood carried on the feathers into the scalding tank.

A small scale settling basin was installed in the early stage of technical development. A full scale settling basin will be installed to provide for effective waste water management and control.

SUMMARY OF RESULTS

The establishment of the close relationship between water reduction and control and improved efficiencies of pretreatment methods has been the most important finding in the study thus far. By reducing the flow of water and the variation in that flow, efficiency of the feather screen, offal screen and settling basin has been increased. This relationship is illustrated in Figure 2 which shows water use and waste loading on a per bird basis.

The following reductions in total water use and waste loadings in the waste water have been achieved:

> Reduction in water use from 850,000 gallons per day to 620,000 gallons per day.

Table 3. Water reduction development activities by area of the plant and changes in fresh water use

Area of plant	Activity	Reduction in fresh water use	
		From	To
Evisceration	Use of improved nozzles		
	Final bird washers	50 gpm	30 gpm
	Hand washers	285 gpm	100 gpm
	Cycling of side pan wash	90 gpm	30 gpm
	Rearrangement of giblet handling	360 gpm	320 gpm
Scalding and defeathering	Use of improved nozzles in whole bird washers	45 gpm	30 gpm
	Substitution of recirculated eviscerating flume water for fresh water and new design on feather flume	94 gpm	0
	Use of chiller water in scalder to replace fresh water	40 gpm	0
Cleanup	New high-pressure cleaning system with foam	112,000 gpd	46,000 gpd

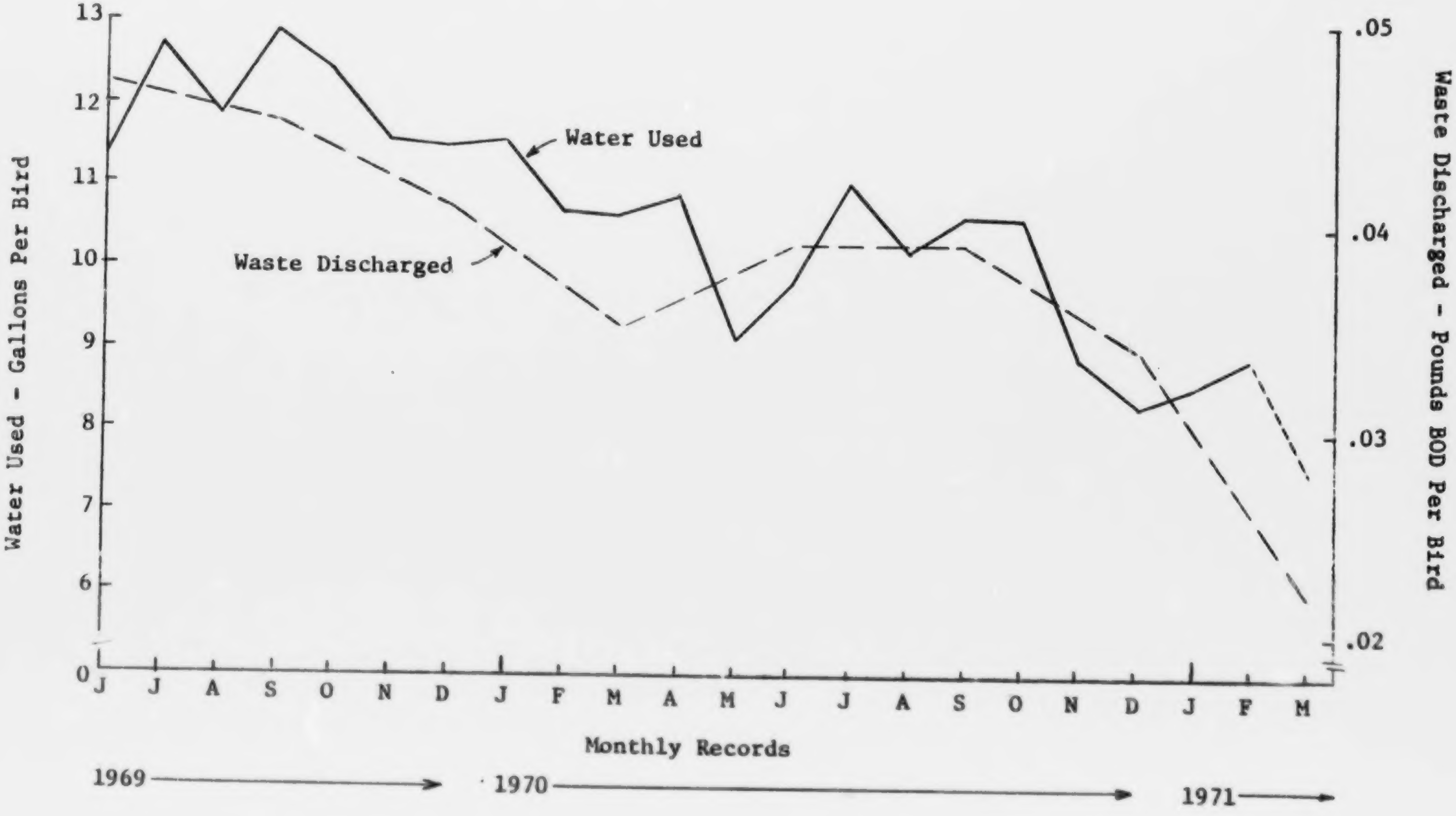


Figure 2. Quantity of Water and Waste Per Bird,
Gold Kist Plant, Durham, N. C.

Reduction in waste load from 4,000 pounds of BOD per day to 1,500 pounds of BOD per day.

Reduction in BOD from 600 ppm to 290 ppm.

Reduction in grease from 200 ppm to 90 ppm.

Blood from the killing room has been effectively eliminated from plant effluent.

Feathers in the plant effluent have been controlled.

The water and sewer rates were increased by 20 percent in July, 1970, and a surcharge of $80 per 1,000 pounds of BOD was added. The surcharge is levied on BOD concentration above 250 ppm. Even with these increases, the water and sewer service costs for the plant have declined. These changes are summarized in Table 4. Further reductions are expected as changes are completed in the blood recovery system and a full scale settling basin is installed.

Table 4. Water, sewer and surcharge costs for selected months

Item	Month	
	July 1969	December 1970
Water	$3,069	$2,157
Sewer	3,377	2,372
Surcharge	--	853
Total	$6,446	$5,382

An evaluation of individual changes is now under way to determine the economic feasibility of each change. A partial budget will be developed for each change and will include an analysis of capital requirements, depreciation, maintenance and operating costs for equipment and process changes. The changes are expected to provide savings in labor and materials as well as reductions in water and waste. There has been a small increase in the level of by-product recovery due to efficiencies in screening, isolation of blood and recovery of grease.

The poultry processing firm can meet restrictions on wastes and reduce surcharges by employing available technology. Development of improved methods can enhance the firm's ability to reduce water use and increase waste abatement.

ECONOMIC ASPECTS OF WATER AND WASTE REDUCTION

The reliance on water and air resources for assimilation of wastes has increased significantly as a result of both a growing population and rising per capita consumption. We would expect that waste dischargers would be permitted to use the assimilative capacity of water, air and land resources as long as these uses are not costly to society. The cost to society has increased to the point that there has emerged a national commitment to reduce pollution.

It now appears that individual firms and municipalities will be required to internalize most, if not all, costs associated with pollution control. A combination of direct restrictions and effluent charges (surcharges) appears to be favored at this time as a means for internalizing pollution control costs.

Water Reduction

The several water reduction methods employed in the plant are listed in Table 3. The incremental cost of water reduction is represented in Figure 3 by the curve MC. Incremental costs will rise in a stepwise fashion as more costly methods are employed. Each method can be evaluated for cost effectiveness by determining the average total cost of each method for reducing water use.

For a firm with incremental cost of reducing water use represented by MC and using the amount of water represented by q_o in Figure 3, water and sewer costs could be reduced by employing water reduction methods until water use is reduced by the amount q_1 (at which point water reduction is q_1 and water use is $q_o - q_1$). At this point, the cost of reducing water use by one more unit is just equal to the cost of purchasing that unit of water.

Waste Reduction

The typical water and sewer rate structure with sewer charges levied as a fixed percentage of the water charge does not provide economic incentives for in-plant management and control of wastes. An increasing number of cities are establishing sewer surcharges to encourage industrial and commercial firms to reduce their volume of waste, to distribute sewage treatment costs more equitably among users and to finance the expansion, construction and operation of treatment systems. Typically, municipalities establish sewer surcharges which are equal to the average total cost of waste treatment.

Waste treatment costs could be reduced by employing waste reduction methods when a surcharge is imposed. An incremental cost curve for waste reduction, MC, is presented in Figure 4 for methods such as in-plant changes and pretreatment. The incremental cost of waste abatement rises at an increasing rate in a stepwise fashion as more costly methods are employed. Development of measures which provide revenue (by-product recovery) or lower costs (process and equipment modifications which reduce labor and

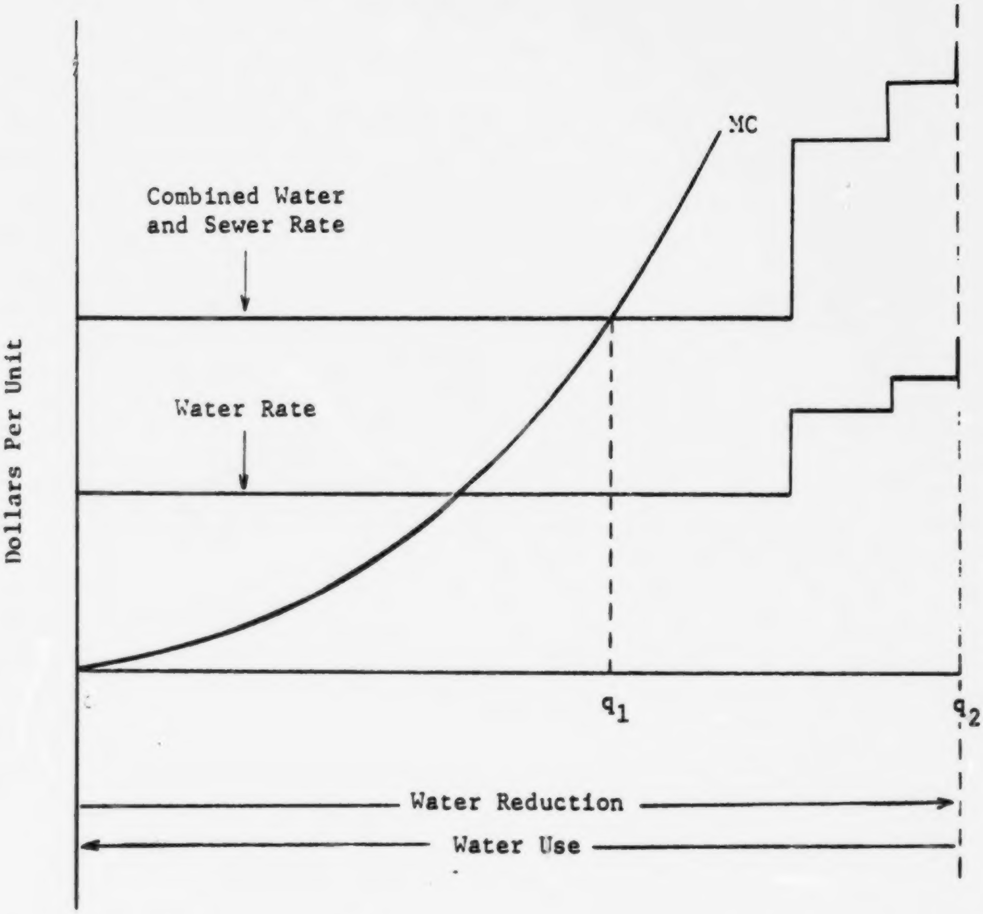


Figure 3. Marginal Cost of Water Reduction

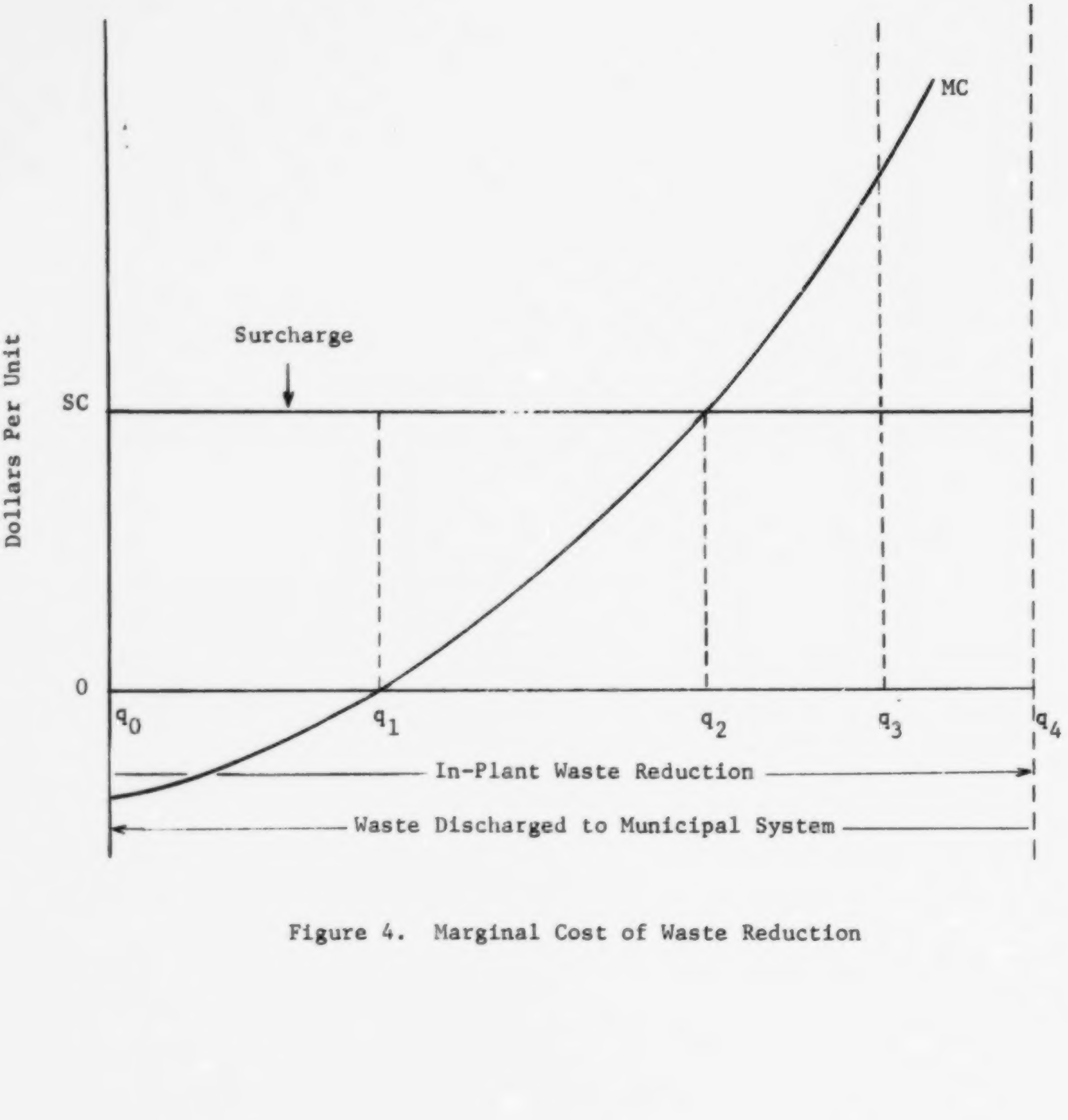


Figure 4. Marginal Cost of Waste Reduction

other input requirements) may result in net earnings from employing waste reduction methods.

The marginal cost curve, MC, shows the added cost of removing a unit of waste by waste reduction methods. The quantity of waste q_1 would be removed in the absence of surcharges if firms had adequate information on waste reduction methods which produce revenue or lower costs. In the absence of surcharges, the remaining quantity of waste $q_4 - q_1$ would be discharged to the municipal system for treatment for the fixed amount of the sewer charge.

When a surcharge is levied, firms would find it profitable to remove an additional amount $q_2 - q_1$ since waste reduction costs are less than surcharge costs. The quantity of waste $q_4 - q_2$ would be discharged to the municipal system for treatment with the quantity $q_4 - q_3$ treated by the city for the fixed amount of the sewer charge. The firm would pay surcharge SC on the quantity $q_3 - q_2$ for a total surcharge of $SC(q_3 - q_2)$.

Combined Water and Waste Reduction

Water and waste reduction are complementary activities. Reducing the amount of water and controlling the regularity of flow increase the efficiency of screens and settling basins and provide an important technical linkage of the interrelatedness of water and waste reduction.

The rate structure for water and sewer services provides an additional linkage between water and waste reduction. If the combined water and sewer rate is less than the surcharge, firms will find it economically feasible to dilute their waste waters and water use will increase. Municipalities wishing to set up a system of surcharges should examine carefully the relative levels of water and sewer rates and the surcharge rate to avoid encouraging water use.

The addition of a surcharge increases the value of water under a typical water and sewer rate structure. As reduction in water purchases occur, less of the waste will be treated as part of the normal sewer charge with surcharges levied on it. This may be more than offset by increased efficiencies in waste reduction methods from reduced water use, however.

There are potentially significant gains to society from research and information programs in water and waste management and control. The typical water and sewer rate structures have encouraged the dumping of waste and excess use of water because of low rates and lack of economic incentives for reducing wastes. Adjustments will occur rapidly as we gain a better understanding of the changes required for effective management of water and waste.

REMOVAL AND RECOVERY
OF
FATTY MATERIALS
FROM
EDIBLE FAT AND OIL REFINERY EFFLUENTS

by

W. C. Seng*

INTRODUCTION

On July 10, 1968 Swift & Company accepted an EPA Research & Development Grant (12060-DQV) of $249,307.00 or 70 percent of Project cost to study the removal and recovery of fatty materials from edible fat and oil refinery effluents at our Bradley, Illinois Plant.

The Bradley Refinery is a modern high volume edible fat and oil refinery engaged in all types of processing. Before the initiation of the Grant, it was equipped with existing standard sewage treatment facilities consisting of a large rectangular Skim Tank unit and an Air Flotation cell comparable in design to a Pacific Separator.

In the United States there are about 250 to 300 plants processing about 18 billion pounds of edible fats and oils annually. The effluent of these plants is principally fatty material which is difficult to treat in present sewage facilities.

The overall objectives of this project were to establish a flexible and complete effluent treatment facility at the Bradley Refinery of Swift & Company, and then to use these facilities to study the use of coagulants, synthetic polymers, cathodic protection devices, proper pH control and other instrumentation in connection with the Skim and Air Flotation units to remove the fatty materials from the plant waste and produce an effluent containing 400 ppm, or less, BOD, ether solubles, and suspended solids.

It was a further principal objective of this project to study a centrifugal system to separate and upgrade the quality of the recovered

---

*Swift & Company Research and Development Center, Oak Brook, Illinois.

Preceding page blank

fatty materials such that a more saleable product could be obtained which would offset part of the cost of the waste treatment. Finally, a complete survey of individual plant waste streams was to be made.

Under the grant, full scale new equipment and modifications were installed costing $150,000 of which $67,000 was for additions to the basic water clarification system. The remaining $93,000 was for the centrifugal oil recovery system.

PROCESS DESCRIPTION

Figure 1 is a simplified process flow diagram for both the water clarification and the oil recovery systems.

Water Clarification System

All the plant waste drains into an existing below ground concrete sump (upper left hand corner, Figure 1) having an effective retention of about 3 minutes at the typical plant flow rate of 300 gpm. From there it is pumped to the Skim unit.

Figure 2 is an over view of the existing Skimmer unit (left side) and the Air Flotation cell (middle). Figure 3 shows the new waste treatment building, the two agitated waste grease collection and treatment tanks, and the storage tank for the dilute acid water phase from the DeLaval centrifuge in the oil recovery system.

Before reaching the Skim Tank, the waste flow (from underground header) passes through a "chemical mixing loop" (Figure 4) consisting of 3 inch diameter pipe arranged as a horizontal hairpin turn. The inlet (bottom) section is Teflon lined pipe, the rest is type 316 stainless steel. Near the inlet end the water phase from the DeLavel centrifuge (oil recovery system) is recycled and injected into the waste stream. Next, 66° Baume sulfuric acid is injected under automatic control for adjustment of the raw waste pH. Five feet downstream from the acid addition point, a 1 gpm sample stream is directed through a Union Carbide pH probe cell (inside the stainless steel metal box). The pH signal inputs to a Union Carbide Water Monitor Instrument (Figure 5) located in the new waste treatment building. The pH signal then inputs to a Foxboro Electronic Controller which, in turn, adjusts the rate of 66° Baume sulfuric acid from a BIF Simplex Propsuperb Pump, (Figure 6). The resultant pH is recorded on an Esterline Angus Multipoint Recorder

The pH control system has succeeded in eliminating the extremes of pH, that is above 9 and below 5, in the skimmer effluent. This degree of control has very substantially improved the typical efficiency of the system. However, closer control would be desirable. But the waste is essentially unbuffered, so the addition of at least a 3 to 5 minute surge tank in the raw waste line would be needed, equipped with a mixer into which acid would be added.

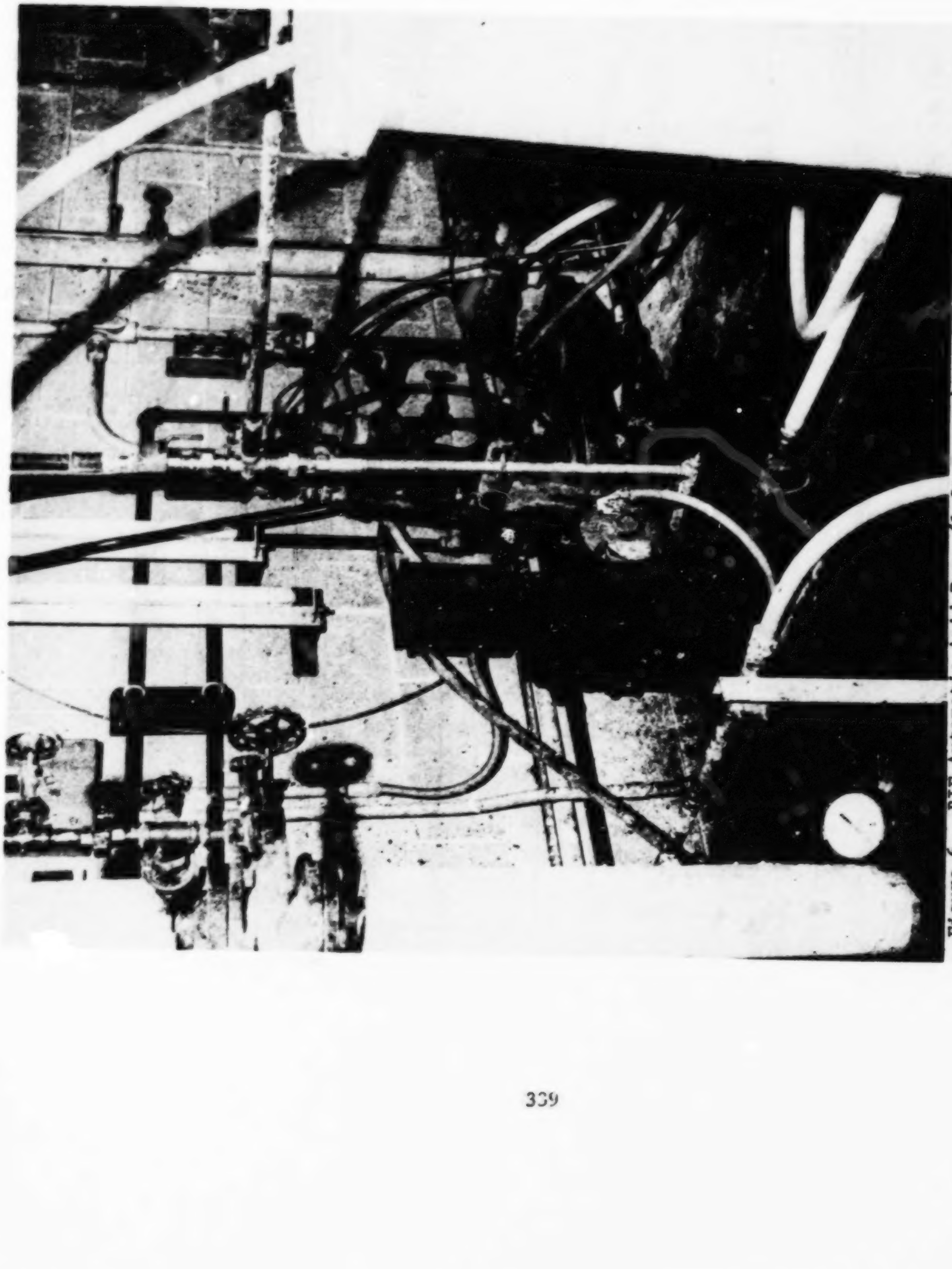
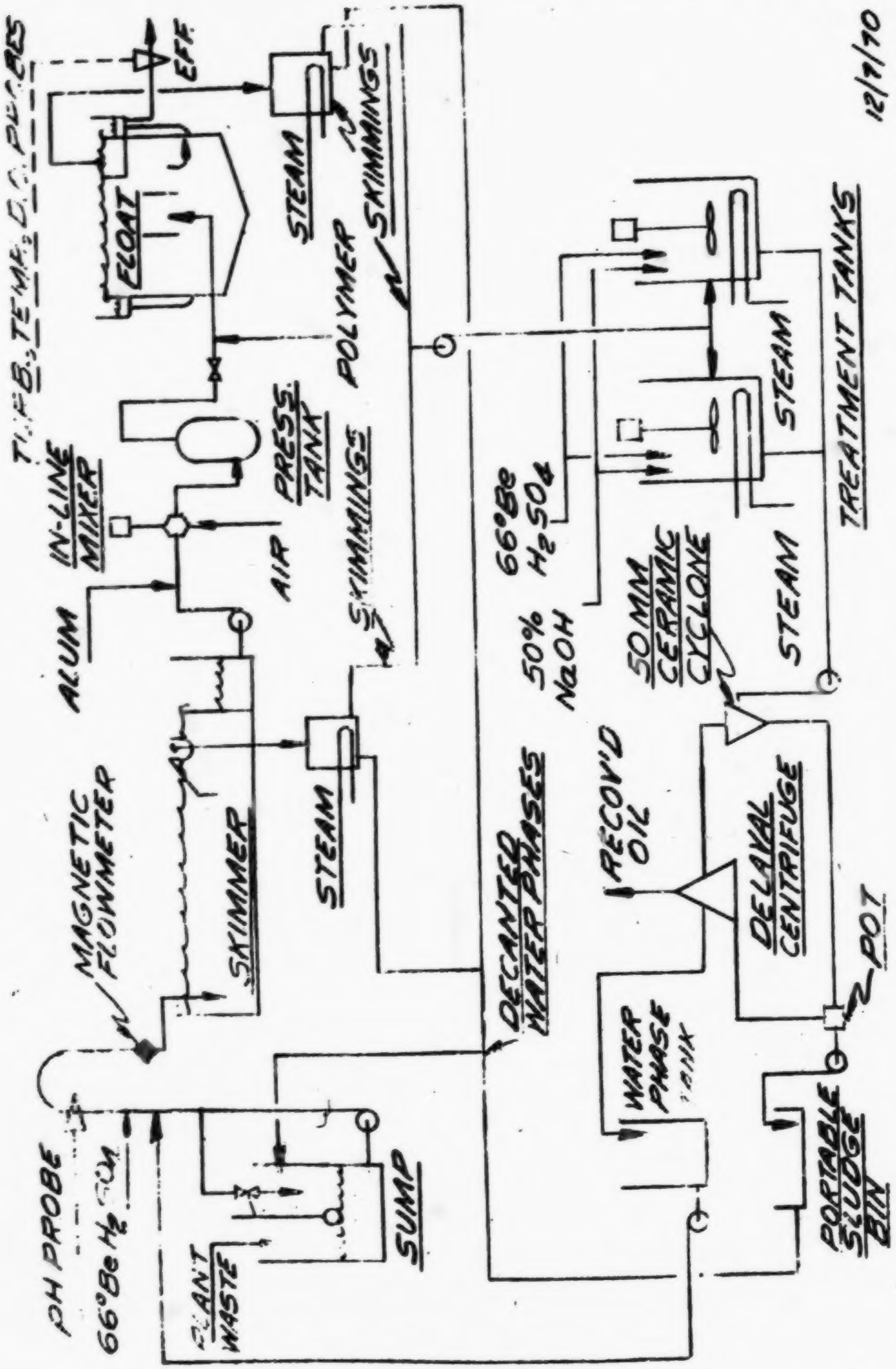


Figure 6. BIF Automatic Acid Pump (left center), and Canned Acid (middle center) and Caustic (right center) Transfer Pumps.



12/9/70

FIGURE 1: BRADLEY WASTE TREATMENT FLOW DIAGRAM

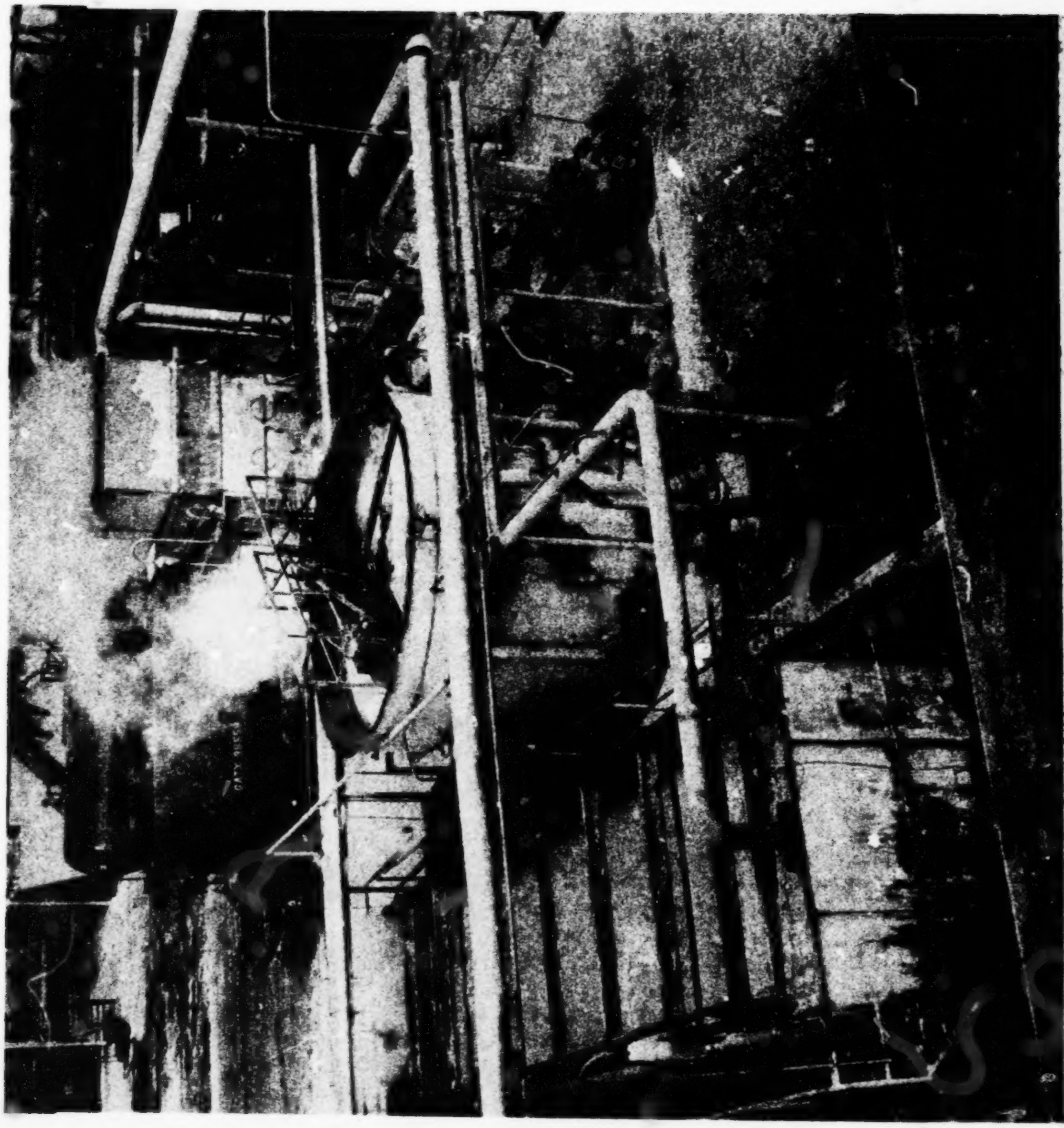


Figure 2. Overall View of Water Clarification System

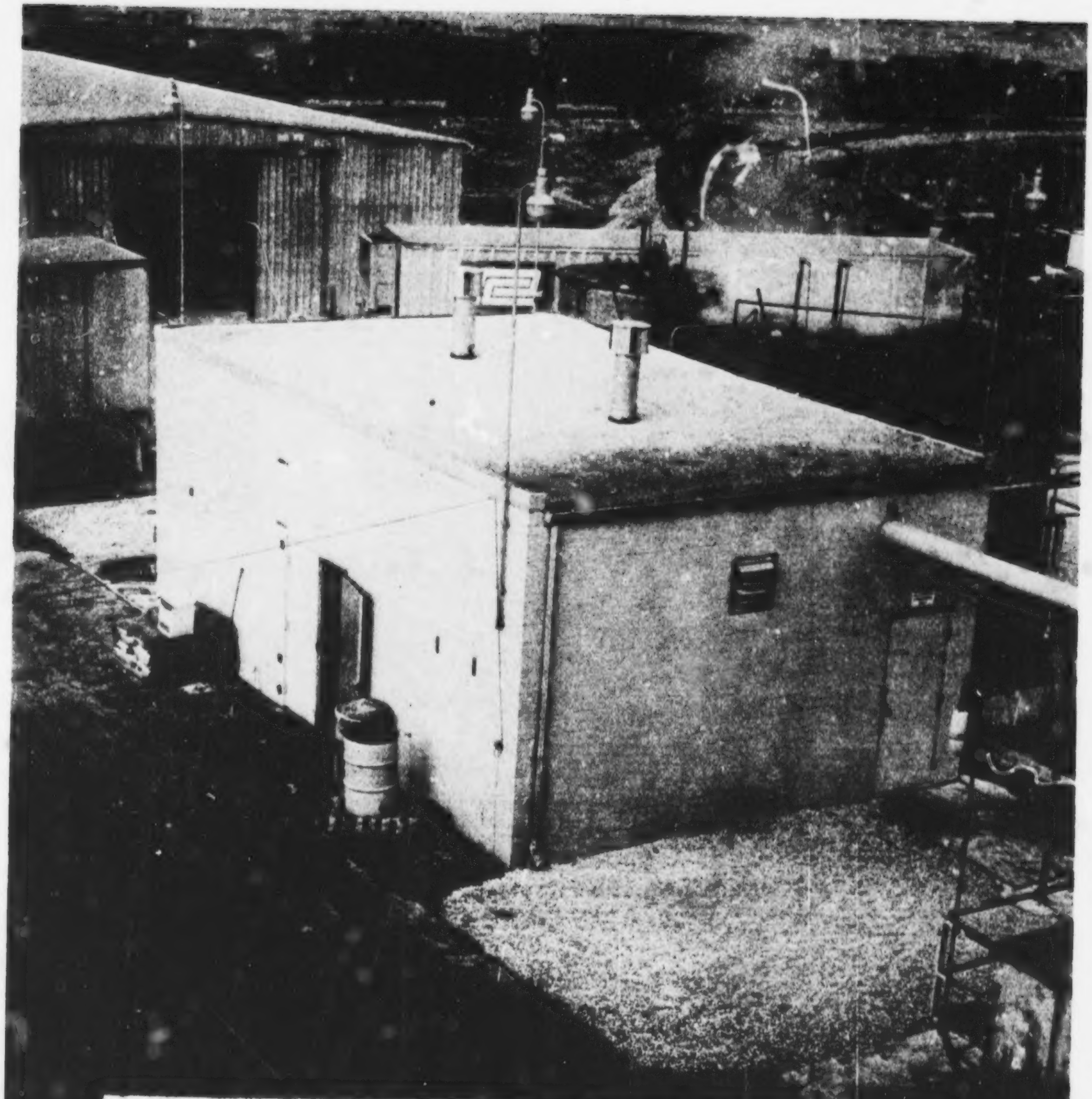


Figure 3. New Waste Treatment Building.

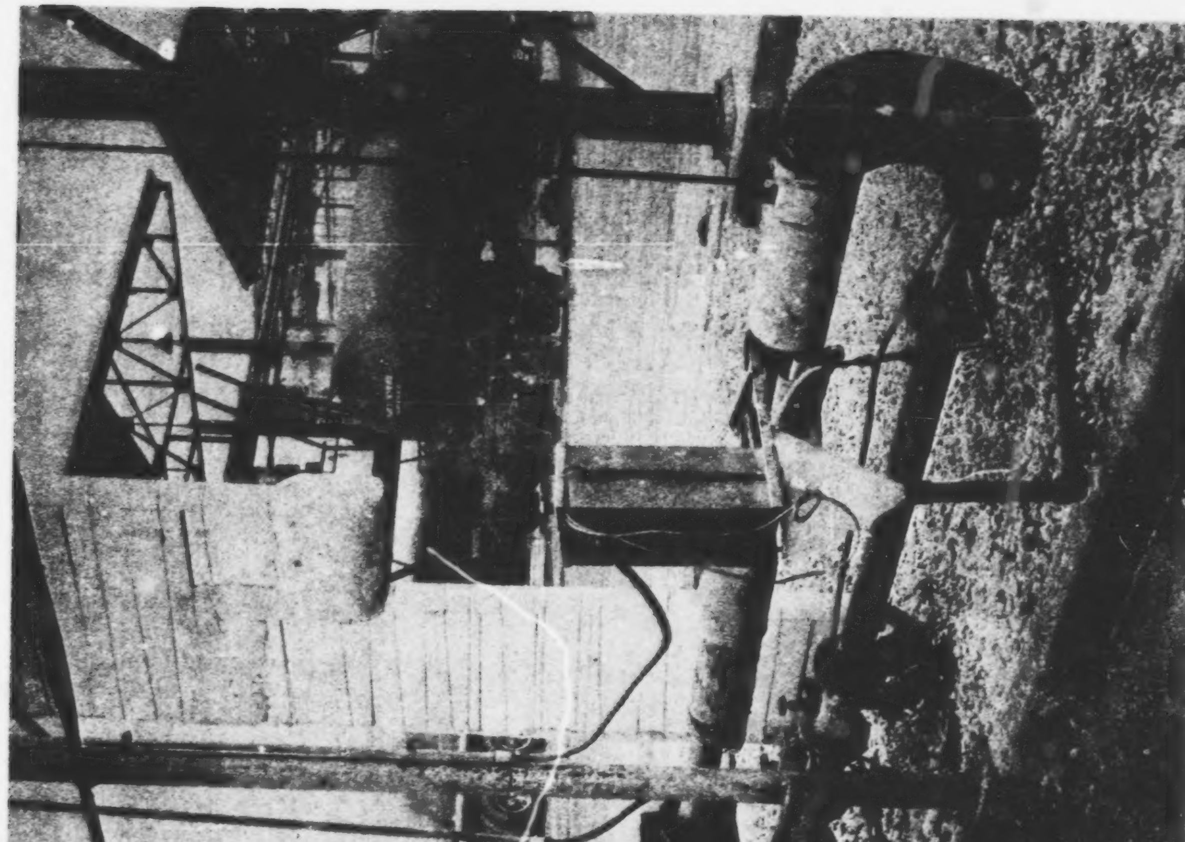


Figure 4. Chemical Mix Loop with pH Probe Chamber, and Magnetic Flowmeter.

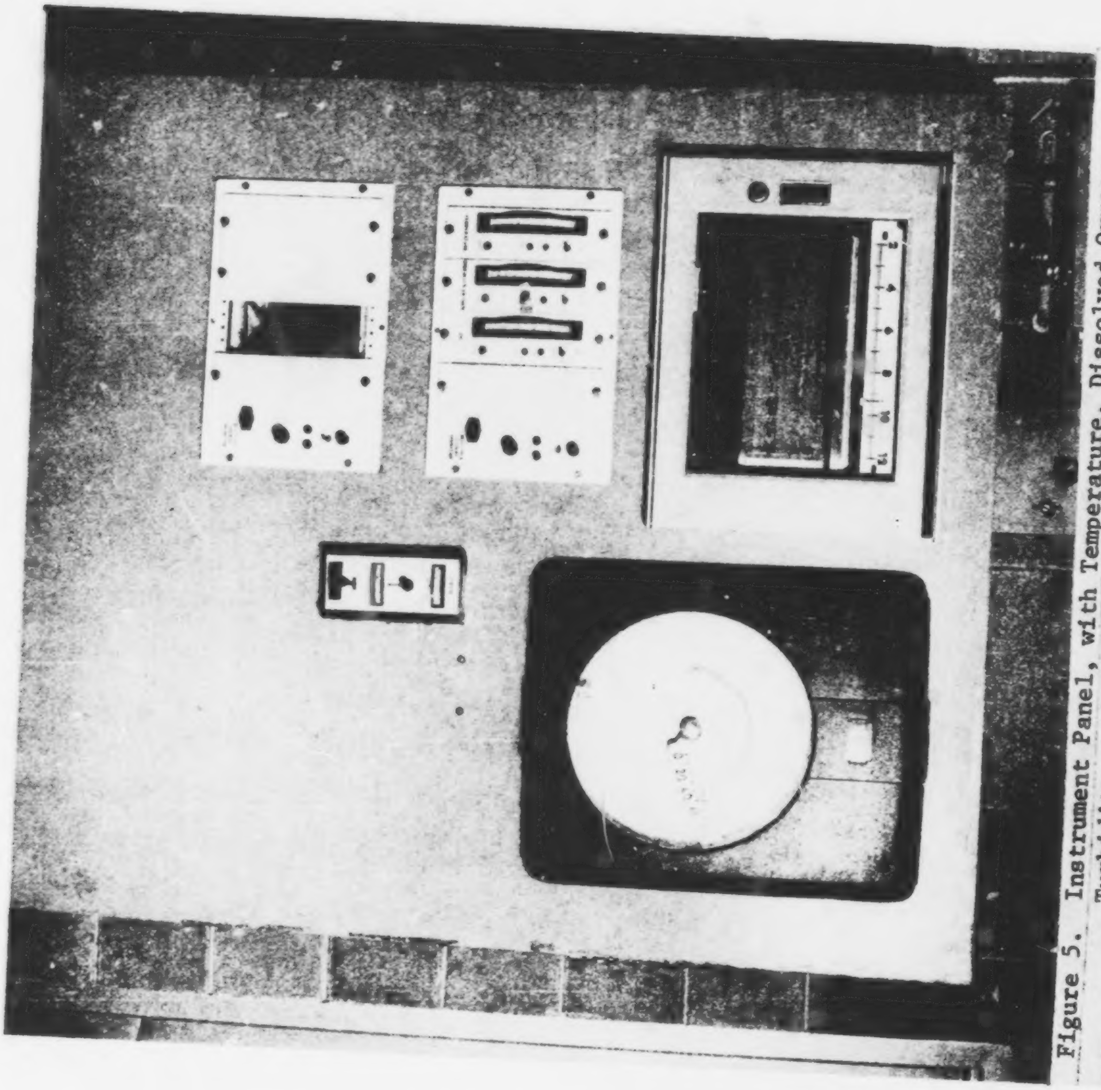


Figure 5. Instrument Panel, with Temperature, Dissolved Oxygen, Turbidity, and pH Indicators (left middle) and Recorder (top left), Magnetic Flowmeter Recorder (top right), and Controller for Acid Pump (lower right).

The waste flow then proceeds around the chemical mix loop in turbulent flow and exits through a Brooks magnetic flow meter with Teflon lining and with a continuous electrode cleaning device. The output of the magnetic flow meter is indicated, recorded and totalized with a Brooks recorder.

The waste flow then proceeds to the Skimmer unit (Figure 7) which has an effective length of 36-½ feet, is 10 feet wide, and has a 5-foot depth for an overall retention time of 46 minutes at 300 gpm. The Skimmer is equipped with surface scraper blades to skim off the grease and deliver it via a conveyor to a steam coil heated 400-gallon tank near the effluent end. No provisions were made in the Skimmer for continuous removal of settled solids. It must be cleaned out approximately once a month.

The water is then pumped to the Air Flotation unit. On the way it passes through a Mixing Equipment Company line blender (Figure 8, far right center). Air is injected directly into the bottom of the mixer under a pressure of 30 to 45 psi at a rate equivalent to at least 4 percent by volume of the water processed. A 20 percent alum solution is injected 20 feet upstream from the in-line mixer.

The waste stream proceeds through a pressure tank, a manual back pressure valve, and then into the flotation cell (Figure 9). A pressure of at least 30 pounds, and preferably 40 pounds, is maintained in the pressure tank. A polymer at 0.2 percent solution is injected just down stream of the manual valve after the pressure tank.

The Air Flotation cell is 13 feet 6 inches in diameter by 10 feet high liquid height, with a retention time of 36 minutes at 300 gpm. Skimmings are discharged by gravity into an 850-gallon steam coil heated steel tank. The clarified effluent discharges by gravity into an underground sump (Figure 2, lower right) from where it is normally pumped to the 200-foot by 300-foot aerated lagoon on the premises. Effluent from the lagoon goes to the Kanakee Municipal Waste Treatment Plant. However, effluent can be by-passed directly to the Municipal Treatment Plant.

Two 300-gallon solution tanks for polymer and one 300-gallon solution tank for alum, with Milton Roy piston type metering pumps for each were located in the new waste treatment building (Figure 10). All tanks are of Atlac 382 polyester fiberglass reinforced construction.

A sample stream of effluent from the Air Flotation unit is pumped to Union Carbide dissolved oxygen and turbidity probe assemblies and a Total Carbon Analyser inside the waste treatment building. A similar temperature probe is located right in the Air Flotation cell effluent.

The temperature probe has functioned reliably, but the turbidity probe was found unsatisfactory primarily because the two halves of the prism came unglued on three occasions. When the unit was operative, it did track the process quite well.

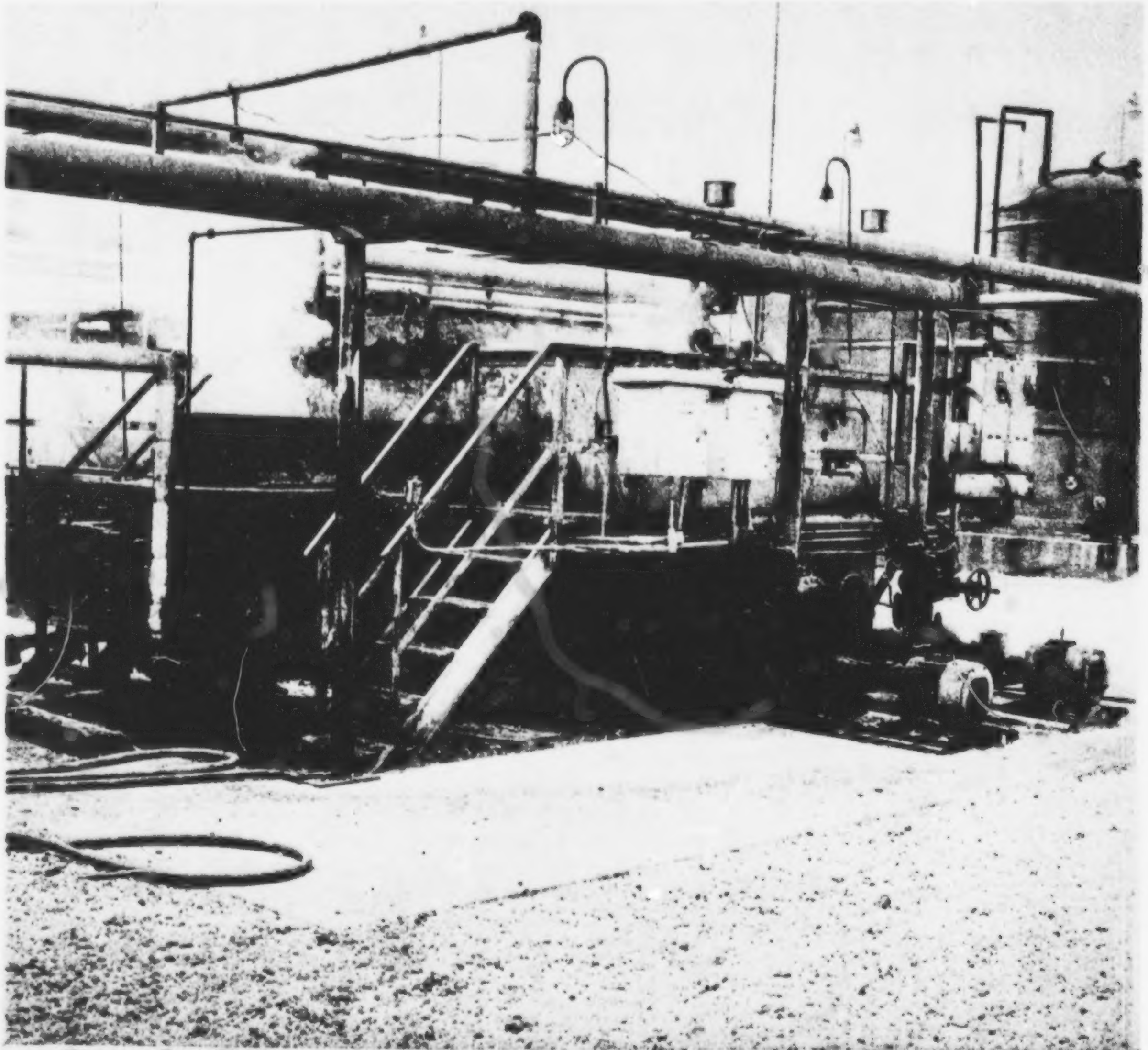


Figure 7. Skimmer Unit, Effluent End, and "Side Tank" for Removed Grease Skimmings (left center).

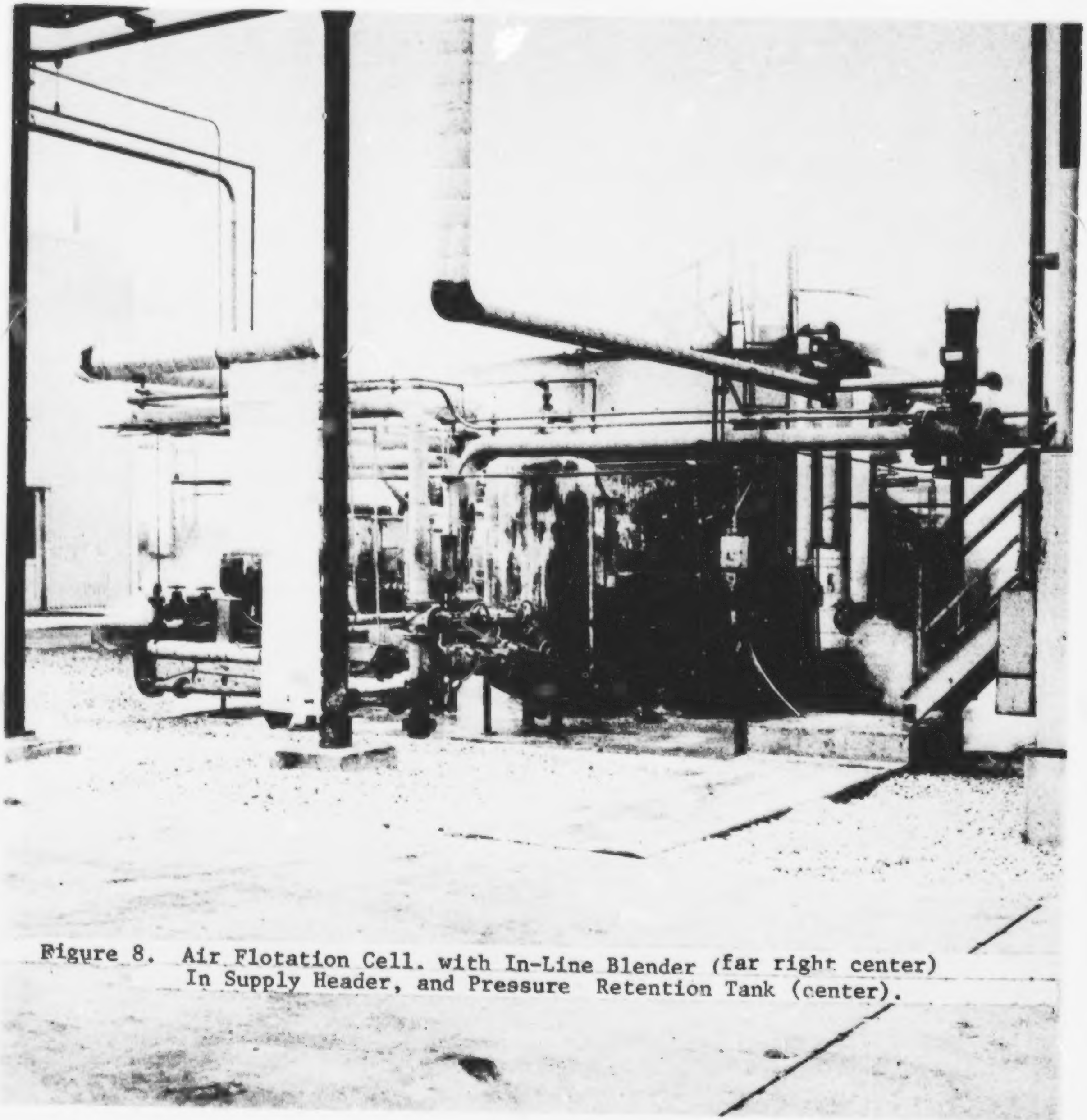


Figure 8. Air Flotation Cell. with In-Line Blender (far right center) In Supply Header, and Pressure Retention Tank (center).

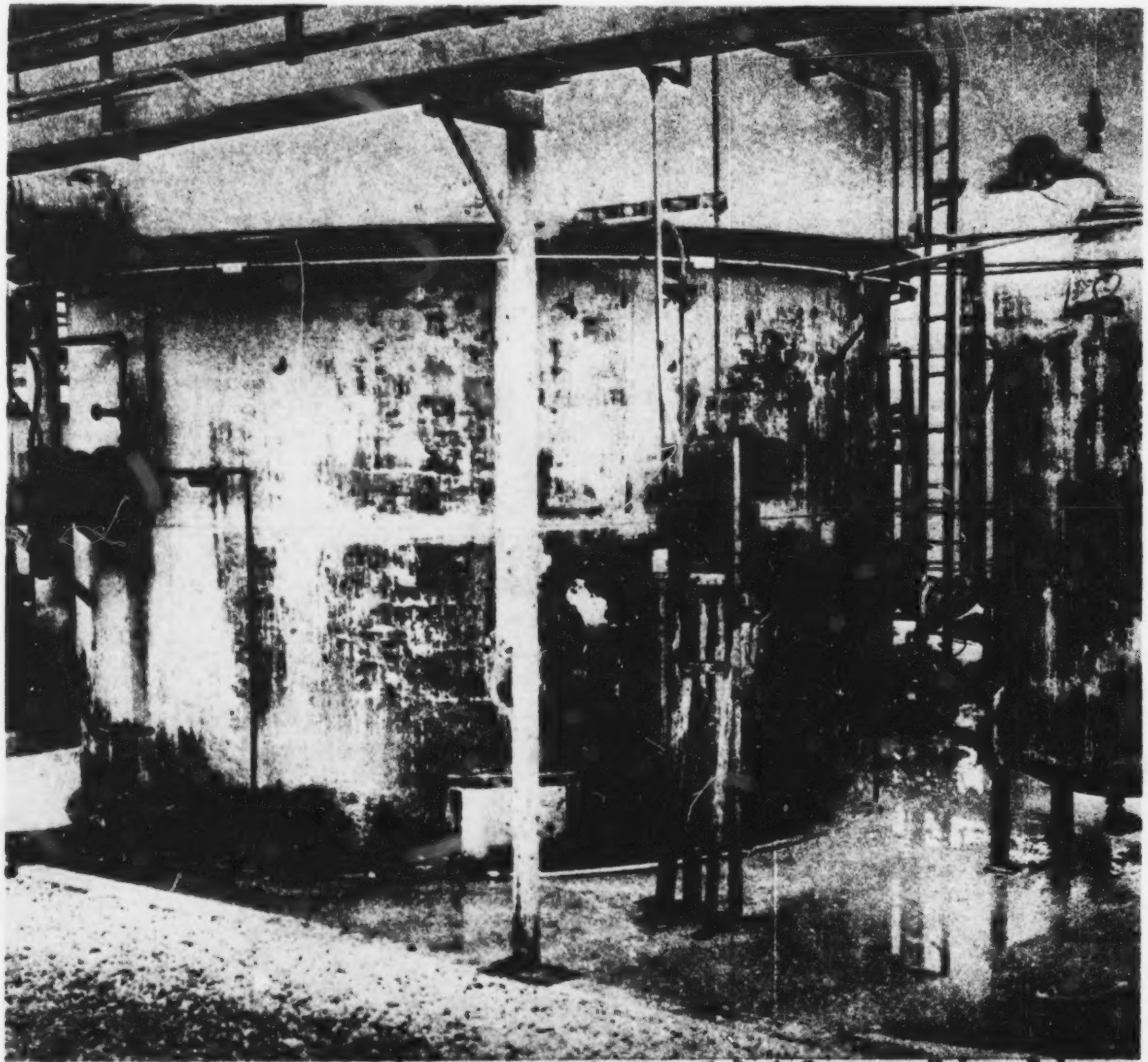


Figure 9. (right to left) Pressure Tank, Manual Back Pressure Valve, Polymer Addition Pipe, and Air Flotation Cell. Treated Effluent Sample Pump (far left center).

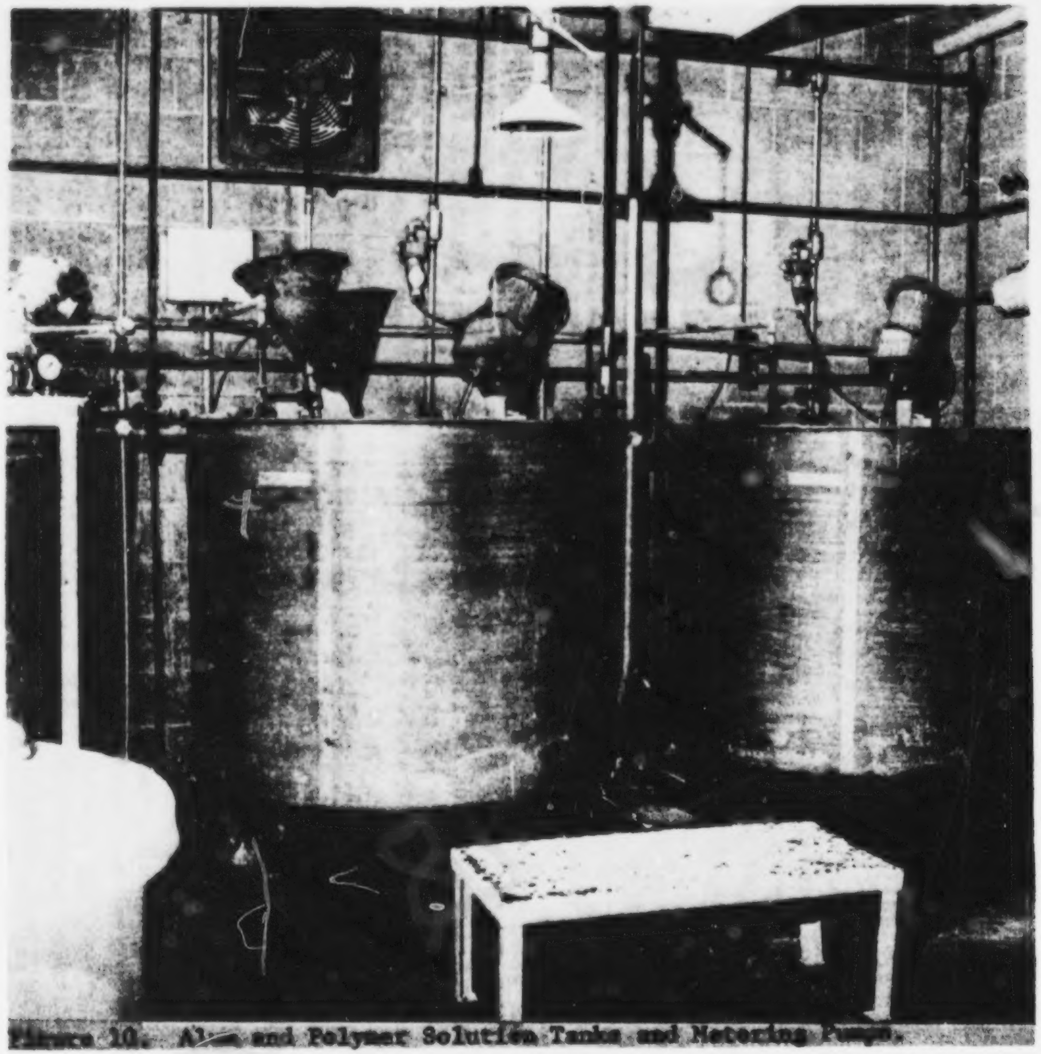


Figure 10. Alum and Polymer Solution Tanks and Metering Pumps.

The dissolved oxygen device functioned quite well except that it required cleaning once an hour to obtain reasonably accurate readings. Usually the dissolved oxygen content of the plant effluent was at saturation.

Total Carbon Analyzer

The Union Carbide automatic total carbon analyzer was investigated heavily over a long period of time. However, it was found unacceptable mainly because its input disc filter and sample measurement orifices became plugged rapidly with the waste grease.

Oil Recovery System

Skimmings from the Skimmer and Air Flotation units are heated and held without agitation in the two "side tanks" as long as possible and are then dewatered to remove about half their volume. The dewatered skimmings are pumped to either one of the two large agitated treatment tanks (Figure 11). Each one is 10 feet in diameter by 11 feet, 9 inches high and has a capacity of 6,500 gallons and can normally accept 24 hours collection of waste grease. While one is being used to collect the grease, the other is chemically treated and centrifuged.

The two treatment tanks are constructed of fiberglass reinforced Atlac 382 polyester resin, with a hairpin steam coil and steam-temperature controls. Each tank has a Mixing Equipment Company Lightnin' Mixer, with a 5 hp motor and two axial flow turbines of 33 inches diameter operating at 84 rpm, all wetted parts of type 316 stainless steel. As the grease is collected, it is heated to 170°F and mixed continuously.

Concerning the steam coils, it became apparent that a heavy build up of cake would form on these coils, requiring maintenance and cleaning every few days. Therefore, to enable direct steam injection, 3/16" holes were drilled in the steam coil, 2 inches apart, directly under the lower agitator impellers. This change for direct steam injection has been quite successful.

When a tank is to be treated, 50 percent sodium hydroxide and 66° Baume sulfuric acid are pumped in and mixed for 15 to 30 minutes, each in succession, bringing the pH first to 10 and then to 2.5.

After treatment, the waste grease is pumped through a 50 millimeter Dorr-Oliver ceramic cyclone and then to a DeLaval Model PX-213 bowl opening, disk stack type centrifuge equipped with automatic cycle controls (Figure 12). The purpose of the ceramic cyclone is to remove as much as possible of the sand and grit from the feed to the centrifuge. The sludge underflow from the centrifuge and the underflow grit stream from the ceramic cyclone are pumped into a portable scavenger bin, having a capacity of 2100 gallons (3 days' operation), located outside the building.

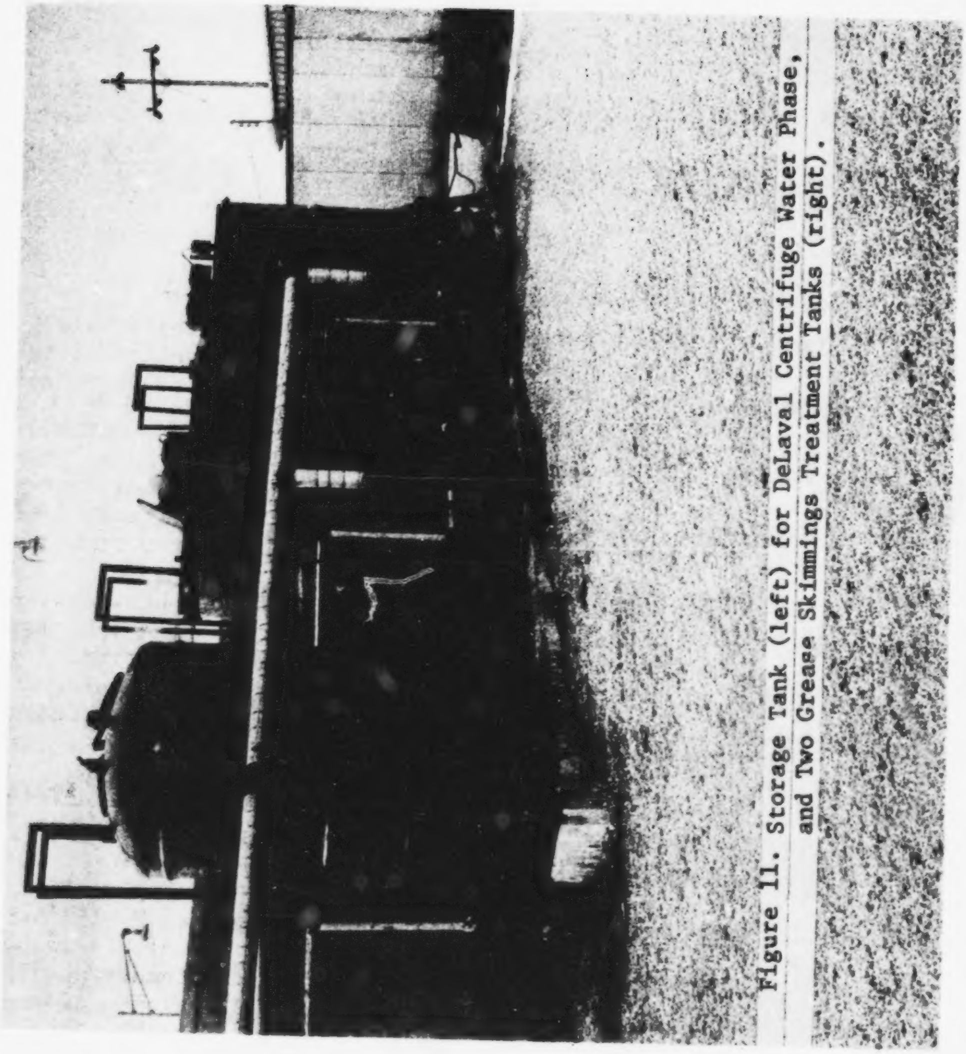


Figure 11. Storage Tank (left) for DeLaval Centrifuge Water Phase, and Two Grease Skimmings Treatment Tanks (right).

The water phase from the DeLaval centrifuge is pumped by the pressure of the centrifuge to a 4700-gallon tank outside the treatment building (Figure 11). It is of the same fiberglass and resin materials as the two treatment tanks, but has no agitator, and has a direct steam injection sparge header and temperature controls. DeLaval acid water from this tank is recycled back to the chemical mix loop of the water clarification system where it partially acidifies the raw waste. The flow rate is adjusted manually to spread the flow over 24 hours of operation.

The clarified recovered oil from the DeLaval centrifuge is pumped to an existing outdoor storage tank.

EVALUATION OF FLOCCULANTS

In general, coagulants such as alum produce a pinpoint sized particle. The role of the polymer is to produce a further agglomeration of these pinpoint particles to a size that will be more amenable to separation.

Laboratory Screening Tests

These polymers (Table 1) were screened in laboratory tests using graduate cylinders to simulate air flotation, along with a Hellige Turbidometer to measure Jackson Turbidity Units. The polymer dosages were 0 and 2.5 ppm, and coagulant dosages ranged from 0 to 500 ppm.

Table 1. Comparison of Different Polymer Systems

(Ranked in Order of Performance)

Polymer	Charge	Mean JTU
Swift X-400	Anionic	512
Swift X-700	Nonionic	571
American Cyanamide P-250	Nonionic	591
Dow NP-20	Nonionic	593
Nalco 673	Nonionic	601
Swift X-420	Anionic	646
Swift X-111	Cationic	685

Anionic and nonionic polymers generally performed better than the single cationic tested, especially at lower pH levels, however, they all performed well, lowering turbidity 10 to 50 percent more than when using coagulant alone. Zinc chloride and alum were both somewhat better then ferric sulfate.

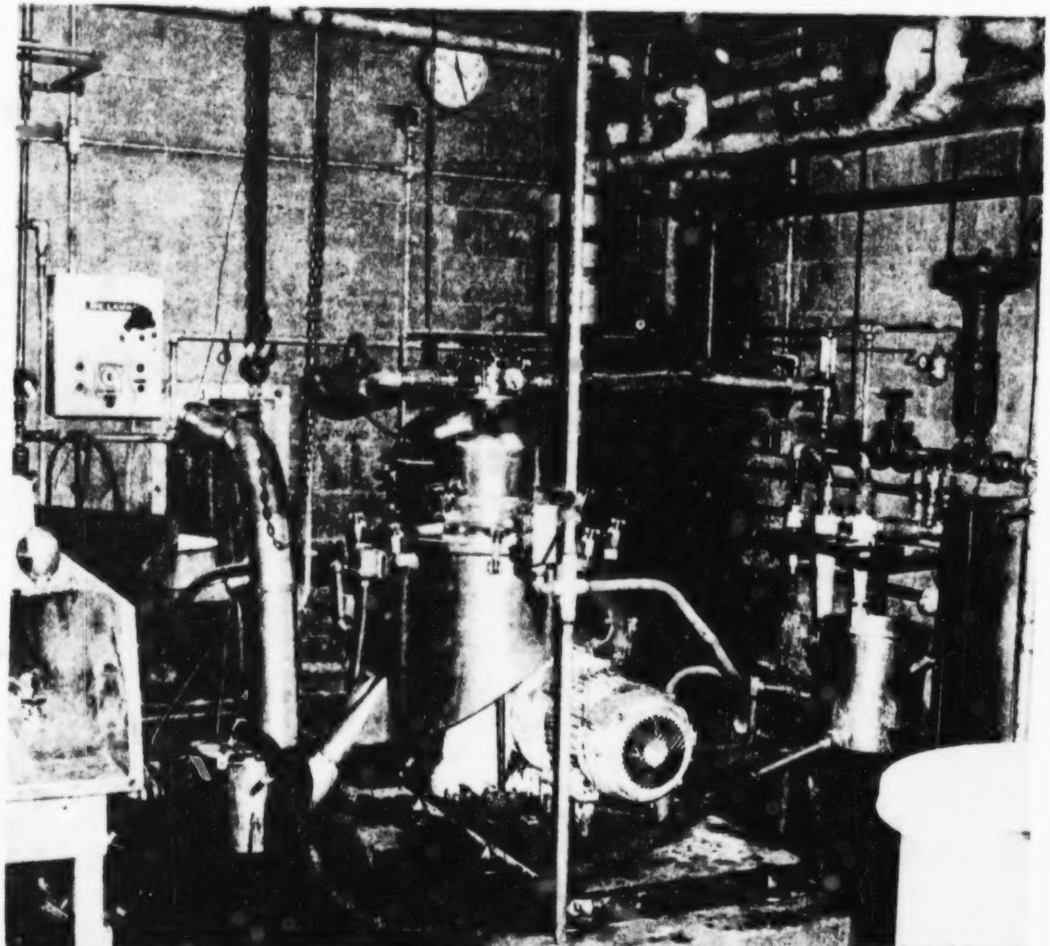


Figure 12. Dorr-Oliver P-50 Ceramic Cyclone (right center), and DeLaval PX-213 Centrifuge.

Sodium aluminate was also tested but was not effective because its addition raised the final pH and increasing amounts resulted in poorer clarity.

Additional laboratory studies were conducted in which the relationships between surface charge, pH, and turbidity were investigated. The effective Surface Potential (ESP) of the clarified phase was determined on a Water Associates' Streaming Current Detector. A typical set of curves obtained (Figure 13) is given where the sample was adjusted initially to 8 pH, then alum treated, followed by addition of 2 ppm Swift X-400 polymer.

All such data suggested that, as expected, the alum required to achieve maximum clarity was reduced as the pH was lowered. The data showed that sulfuric acid alone acts as an effective pre-floc agent for coagulant aid at pH 4. It showed that the point of maximum clarity (or minimum JTU) appears as the ESP approaches zero, but is not necessarily maintained even though the ESP may remain near zero as the curves move from left to right, or in the direction of increasing alum dosage. It was also seen that the point of maximum clarity is often rather sharply defined, particularly in the mid-alum dosage and pH ranges.

To summarize the relationships between initial and final waste pH, alum dosage, and turbidity, when using 2 ppm of Swift X-400, the curve in Figure 14 was constructed from the above data. It connects all points of minimum turbidity for the corresponding final pH. Tie lines are used to show the pH of the waste sample before alum addition. This figure was used as a guide to the best range of conditions to be explored in the Bradley waste treatment system evaluations.

BRADLEY FLOCCULATION TESTS

Based upon the laboratory screening tests above, four polymers were selected for field evaluation, namely: Swift X-400, American Cyanamid P-250, Dow NP-20, and Nalco 670. Except for brief tests with ferric sulfate, alum was used exclusively as the coagulant. The tests with ferric sulfate showed that, although results were good and required perhaps somewhat less dosage compared to alum, considerable difficulty was experienced in putting the ferric sulfate into solution and in handling the sludge remaining. Furthermore, the ferric sulfate colored the resultant recovered oil red. Zinc chloride was not used because of concern over potential toxicology questions. Sodium aluminate was not used because of the negative laboratory screening tests mentioned earlier.

General Procedure

The tests were set up on a shift basis. Composite shift samples were analyzed. The manually adjusted Milton Roy metering pumps for the alum and polymers were set to maintain constant dosages corresponding

Figure 13.

EFFECTS OF INITIAL pH AND ALUM DOSAGE
ON CLARIFIED PHASE

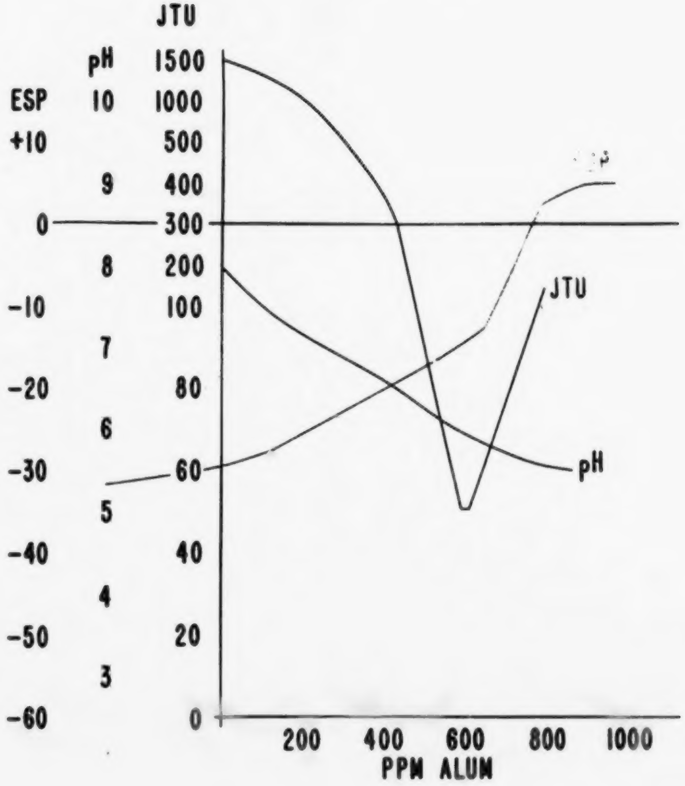
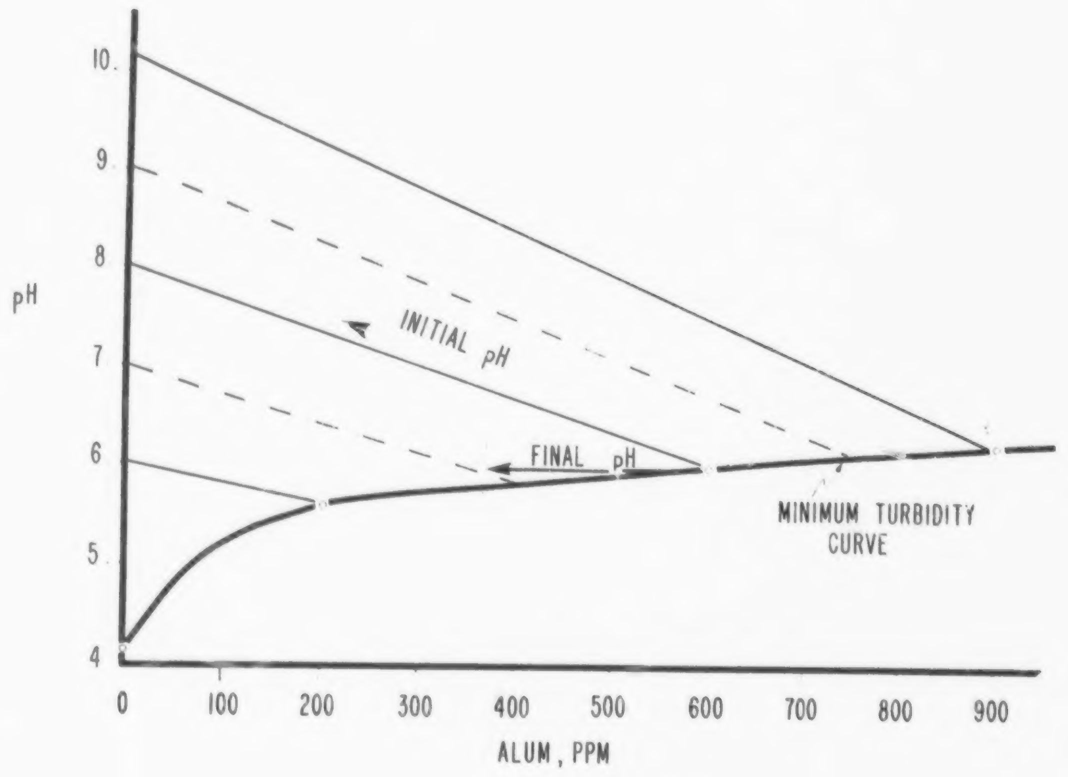


Figure 14.

MINIMUM TURBIDITY CURVE, AND INITIAL pH, FINAL pH, AND ALUM DOSAGE REQUIRED



to the total waste in-put flow rates as measured by the Magnetic Flow meter. The pH of the raw waste was controlled at levels per the aforementioned Figure 14 to yield maximum treated effluent clarity as much as possible.

The recovered skimmings were collected over a 24-hour period while only one polymer was used. Then the skimmings were processed through the centrifuge. In all, 184 shifts of data were obtained.

During the entire period the cathodic protection devices were in operation at standard conditions.

Evaluation of Flocculant Test Data

All the data was subjected to statistical evaluations facilitated by the use of a computer. Overall average data for each shift were not greatly different. For this talk, average data for the 4:00 p.m. to midnight shift are shown in Tables 2 and 3, beginning with the raw waste. Flow rates actually varied from 100 to over 600 gpm, and contaminant concentrations were up to 10 times the average shown.

Air flotation effluent contained an overall average of 401 ppm suspended solids, 357 ppm ether solubles, and 741 ppm BOD.

Removal efficiencies for the Air Flotation cell were generally 2.5 times as high as for the Skimmer unit, i.e. 70 to 88 percent compared with 20 to 40 percent. Overall removals of contaminants were 84.0 to 89.4 percent for suspended solids, 87.2 to 92.4 percent for ether solubles, and 74.9 to 81.6 percent for BOD. Overall BOD removals were typically 10 percent lower than for suspended solids and ether solubles. This is explained in part because 50 to 150 ppm soluble BOD are contained in the raw waste which the system does not remove.

Table 2. Averages, All Data, Afternoon Shift Bradley Flocculant Tests

Raw Waste

Gal.	138,407
gpm	288
pH	9.0
Sus. Solids. ppm	3,679
Ether So., ppm	3,984
BOD, ppm	4,012

Skimmer Effluent

pH	6.5
Sus. Sol., ppm	2,706
Sus. Sol., % removed	32.6
Ether Sol., ppm	3,195
Ether Sol., % removed	25.3
BOD, ppm	2,439
BOD, % removed	38.3

Air Flotation Effluent

Temperature	111
Alum, ppm	452
Polymer, ppm	2.59
pH	5.0
Sus. Sol., ppm	401
Sus. Sol., % removed	84.3
Ether Sol., ppm	357
Ether Sol., % removed	88.3
BOD, ppm	741
BOD, % removed	70.3

Table 3. Percent Overall Contaminent Removals

	Shift		
	Midnight	Morning	Afternoon
Suspended Solids	84.0	86.7	89.4
Ether Solubles	87.2	92.4	91.2
BOD	74.9	77.0	81.6

In summary, regression analyses performed on all the data led to the following conclusions:

1. Best results were achieved for both the Air Flotation cell and the Skim tank when the final Air Flotation pH was in the range of 3.5 to 6.0.

2. Concerning the Air Flotation cell, good results generally were obtained at all alum dosages ranging from 100 to 700 ppm, provided the pH of the stream was consistent with the 3.5 to 6.0 range.

3. The polymers all generally performed essentially equally well at all dosages used. These data suggest that no more than 2 ppm need be used as a practical matter.

4. The Bradley system, given the present waste load, is substantially undersized to produce a waste consistently under 400 ppm of all contaminants, particularly BOD.

COMPARATIVE COST FOR POLYMER FLOCCULENTS AND COAGULANTS

Table 4 lists comparative costs for the four polymers tested at the Bradley system. Also given is the cost at a dosage of 1 ppm polymer in 500,000 gallons of treated water. Note that there is relatively little difference in the daily cost for polymers.

Table 4. Costs for Polymers

Polymer	Pounds	Cost/Pound	Cost/500,000 Gal.
Swift X-400	5,000 up	$1.65	$6.87
Am. Cyan. P-250	5,000 up	1.40	5.83
Dow NP-20	5,000 up	1.55	6.46
Nalco 670	5,000-19,999	1.26	5.25

Table 5 lists costs for various coagulants, and daily costs to treat 500,000 gallons at 100 ppm dosage. Note that alum is the least expensive.

Table 5. Costs for Coagulants - Truckload Quantities

Coagulant	Cost/Pound	Cost/500,000 Gal.
Alum, powder	\$0.0300	\$12.50
Zinc Chloride, granular	0.1415	58.94
Ferric Sulphate, powder	0.0455	18.95
Sodium Aluminate, pulverized	0.1270	52.90
Ferric Chloride, powder	0.0650	27.07

INFLUENCE OF CATHODIC PROTECTION DEVICES

The cathodic protection system was operated during the entire period when data was collected for evaluation of flocculants.
Summary results were:

1. Corrosion was brought under control in all areas where cathodic protection was installed.

2. Metal surfaces below the water line remained free of adhering deposits of fat and scale whereas previously a thick, firm cake would form.

3. Concerning the effect of impressed current on flocculation efficiency, the "noise" of the process variables prevented clear cut results as to a beneficial effect on effluent contaminants content. Nevertheless, based upon extensive laboratory and field work in other and similar applications, particularly in recent months, impressed current does produce valuable benefits on flocculation and clarification of waste waters.

OIL RECOVERY SYSTEM EVALUATION

When a tank was to be treated and processed, the pH was adjusted to 10, minimum, using 50 percent sodium hydroxide and allowed to mix for a period of approximately a half hour. Then the pH was adjusted to approximately 2.5 by the addition of concentrated 66° Baume sulfuric acid. Again, it was mixed for a period of up to a half hour. For several tests, only concentrated sulfuric acid was used to lower the pH to 2.5.

Initial Test Runs

Initial test operations showed that a 122 millimeter ring dam was too large and would not provide good separation under any conditions. Additionally, it was found that the machine must be operated with a rather dilute sludge discharge so as to prevent caking and build-up of solids within the bowl and serious errosion of the bowl periphery.

It became clear that the presence of filter aids and asbestos fibers used in the plant operations plugged up the vertical distribution holes in the centrifuge disc stack and caused considerable errosion. Therefore, Dorr-Oliver 50 millimeter and 25 millimeter ceramic cyclones and a Bauer 3-inch diameter nylon cyclone were installed and tested for removal of at least part of the fibers and gritty material from the waste grease feed.

Final Tests

All subsequent tests were made using a 119, 116, and 114 mm ring dam along with the 50 mm cyclone. The feed was shut off each time the bowl was opened to "shoot", or discharge, the sludge phase. The general results were as follows:

1. Neither oil quality nor oil recovery were affected significantly by typical range for feed rate and composition. A pH of 2.5 and a 180°F temperature were found optimum.
2. Equivalent results were achieved without using sodium hydroxide in the chemical treatment but rather using sulfuric acid alone. When only sulfuric acid was used, less than half was needed.
3. Best performance was achieved when using a 114 millimeter ring dam. Furthermore, no smaller ring dam is indicated.
4. a 45 second "on feed' cycle time was optimum.

Table 6 gives typical operating and analytical data for the oil recovery system when using the 114 millimeter ring dam and a 45 second "on feed" cycle plus 15 seconds "shoot" time for a total of 1 minute per cycle. The recovered oil phase contained an average of 0.8 percent moisture, 98.9 percent ether solubles, 0.3 percent ether insolubles, and 0.13 percent ash.

Table 6 also shows 88.9 percent of the oil in the feed as ether solubles was recovered in the oil phase. Only 1.9 percent of the original ash content went to the oil phase. The water phase typically contained 1.8 percent of the original ether solubles and 43.1 percent of the original ash. The total sludge contained 3.4 percent of the original ether solubles and 50.8 percent of the original ash. About 38 percent of the ash removed in the total sludge was removed by the

Table 6. Typical Oil Recovery System Data

	Feed	Oil	Water	Cyclone Sludge	DeLaval Sludge	Total Sludge
Rate, lb./min.	114	29	44	15	26	41
Analyses						
Moisture, %	67.0	0.8	95.0	90.6	93.1	92.1
Ether Sol., %	28.3	98.9	1.3	4.4	2.3	2.7
Ether Insol., %	4.7	0.3	3.7	5.0	5.1	5.2
Ash, %	1.7	0.13	1.9	2.4	2.3	2.4
Distribution						
Ether Sol, to. %		88.9	1.8	2.0	1.8	3.4
Ash to, %		1.9	43.1	18.6	30.9	50.8

cyclone. It is believed that at least 70 to 80 percent of the coarser particles were removed in the cyclone underflow, thereby nearly eliminating errosion.

Actually, over 95 percent of the ether solubles would be recovered since only one half the sludge is lost after dewatering. The decanted water from the sludge, plus the water phase from the centrifuge, are recycled to the process.

Additional quality analyses are given in Table 7.

Table 7

AVERAGE ADDITIONAL QUALITY ANALYSES FOR THE DELAVAL RECOVERED OIL

FFA,%	FAC Color	Titer	Sap. No.	Unsap, %	Iodine Value
21.9	21	34.9	198.2	2.5	65.2

The indicated value today of this oil for soap or animal feed uses is in the range of 4-1/4 cents to 6-1/2 cents per pound. At 4-1/4 cents, to be conservative, and based on a recovery of 7,000 pounds of oil/day for 250 operating days (excluding weekend operations), a total 1,750,000 pounds annually would be recovered, having a value of $74,000.

ECONOMIC EVALUATION

Direct operating costs for the Bradley Water Clarification are shown in Table 8, based on 500,000 gallons per day and Monday through Friday operation. Annual depreciation charges were not included. However, they would represent a minor percentage.

The total daily direct operating cost for the Water Clarification System is $328, of which 38 percent is for chemicals, 5 percent for utilities, 46 percent is for direct labor, and 11 percent is for maintenance.

The total Waste Treatment System is actually operated 7 days a week. However, on weekends the waste load from the plant is substantially lower. However, it is believed that the direct operating costs shown give a good representation of the situation.

Table 8. Direct Operating Costs For Water Clarification

Basis: 500,000 GPD Waste Flow, Monday through Friday.

	$/Day	%
Alum, 500 ppm, $0.03/lb.	62	19
Swift X-400 Polymer, 2 ppm, $1.65/lb.	13	4
Sulfuric Acid, 66° Be. 1700 ppd, $0.03/lb.	51	15
Power, 1370 Kw hr., $0.0094/Kw. hr.	13	4
Steam, 3000 ppd, $1.00/1000 lb.	3	1
Labor, 1 man/shift, $6.29/hr. (incl. fringes but not supervision or material handling)	151	46
Maintenance (excluding depreciation)	5	11
Total	328	100

Total direct operating cost for the Oil Recovery System, Table 9, is $171. of which 5 percent is for sulfuric acid, 29 percent for disposal of the combined centrifuge and grit cyclone sludge (after removing approximately 50 percent of its volume by decanting), 10 percent for utilities, 44 percent for direct labor, and 12 percent for maintenance. The 7,000 pounds of reclaimed oil obtained each day with a value of 4-1/4 cents per pound would yield $300 per day, or 60 percent of the grand total waste treatment direct operating costs of $500 per day.

Table 9. Direct Operating Costs for Oil Recovery

Basis: 500,000 GPD Waste Flow, Monday through Friday.

	$/Day	%
Sulfuric Acid, 66° Be. $0.03/lb	8	5
Sludge Disposal, $150/2100-gal. load/3 days	50	29
Steam, 3000 ppd. $1.00/1000 lbs	3	2
Power, 1440 Kw hr., $0.0094/Kw hr.	14	8
Direct Labor, 1.5 men/day, $6.29/hr.	76	44
Maintenance (excluding depreciation)	20	12
Total	171	100

At the present time, inedible oil and tallow prices are about 25 percent above the average for the past 10 years. However, it is also felt that the recovered oil may find a market where its value would approach 6 to 6-1/2 cents per pound at present day prices. In any case, it is believed a fair assumption that over the years, the value of the recovered oil can be expected to offset at least this indicated 60 percent of the direct operating cost of such a waste treatment facility.

It will be noted that the cost of alum and sulfuric acid represent a high percentage of the overall daily operating cost. The price of 3 cents per pound for alum was for 100-pound bags in quantity. The price of sulfuric acid is for 55-gallon drums at 3 cents per pound. Both costs can be reduced significantly if bulk quantities and storage are used.

IN-PLANT SURVEY

Turning now to the in-plant survey, all the waste, except sanitary waste, enters the treatment system via a single hot well. Plant interior operations which generate wastes consist of caustic refining, bleaching, hydrogenation, and deodorization of vegetable oils, mainly soybean, but also cottonseed, corn, peanut, and palm oils: shortening and margarine manufacturing and packaging, and a large indoor tank farm area. The outdoor facilities consist of many storage tanks for raw materials plus a tank car and tank truck loading, unloading, and washing area.

Time will not permit a detailed discussion, so to summarize, the survey showed that the great bulk of waste flow and loading results from general cleaning operations indoors and outdoors. Small amounts come from the basic refining, hydrogenation, bleaching and deodorizing operations.

Relationships between Production and Waste Load

Table 10 gives average and range production data for each production area in thousands of pounds per 24-hour day, covering 42 days of operations.

No correlations were found with waste flow or loading for individual production areas or grand total production.

Table 10. **Production Data for Bradley Refinery**

Production Area	Production, 1000 lb/24 hr.	
	Average	Range
Caustic Refining[A)]	541	265-990
Hydrogenation	290	165-385
Bleaching	630	270-980
Deodorizing	815	601-946
Shortening Manufacturing	552	449-661
Margarine Manufacturing	156	92-205

A) All oils processed.

BIOLOGICAL TREATMENT OF HIGH BOD YEAST WASTES

by

Thomas P. Quirk*

EFFLUENT LOADINGS & CHARACTERISTICS

Source of Effluents

Manufacturing processes at the Production Facility included: production of yeast, vinegar, baking powder, soups, seasonings, and the bottling of alcoholic beverages.

Waste effluents were discharged in a variable pattern during the period from 12:00 a.m. Monday to approximately 3:00 p.m. Friday.

The major portion of the BOD and flow loadings were attributable to the yeast production processes. These processes included: molasses clarification, fermentation and separation, equipment sterilization, and yeast packaging. Spent beers resulting from the separation of yeast from the fermentation liquors accounted for well over 90 percent of the total plant effluent BOD.

Equipment sterilization and molasses clarification began early Monday morning. The first fermentations of the week's production were completed late Monday morning, and the first discharge of separator beer followed immediately. The cycle of fermentation and separation continued until early Friday morning. Equipment sterilization and plant cleanup began at the cessation of the last separator beer discharge and continued until late Friday afternoon. No process effluents normally occurred from Friday evening until late Sunday evening.

Daily Waste Loadings

Waste loadings during production periods were highly variable. BOD concentration variations as high as 5 to 1 were experienced. The unpredictability of daily effluent data required statistical analyses for the development of process design loadings.

A statistical analysis in terms of loading averages and variations from the average is shown in Table 1.

---

*Quirk, Lawler & Matusky Engineers, New York, N. Y.

Table 1 Analysis of Daily Waste Characteristics

Item	Mean Value ppm	Variation* as a Percent of the Mean
1. Effluent BOD	5300	70 to 130%
2. Effluent COD	7500	65 to 140%
3. Effluent Suspended Solids	780	60 to 150%

*Variation = Range of values encompassed by + or - one standard deviation about the mean.

The average concentrations of the separator beer components and their relative contributions to the total plant effluent are shown in Table 2. Separator beers represent approximately 64 percent of the daily effluent volume and 94 percent of the daily BOD discharge. Effluent flow rates varied over any 24 hour period. A range of 200 gpm to 1500 gpm was observed during production hours. During periods of intense rain, effluent peaks exceeded 2000 gpm for short durations.

Table 2 Summary - Effluent BOD & Flow Components

Source	Percent Relative Volume	Percent Relative BOD	Approximate BOD Source ppm	Concentration of: Remainder ppm
1. First Separation Beer	25	78	17,400	1,600
2. First and Second Separation Beers	47	90	10,000	1,040
3. First, Second and Third Separator Beers	64	94	8,000	900
4. Composite Waste	100	100	5,400	-

Miscellaneous Waste Characteristics

Temperatures of the effluent exhibited seasonal variation. Monthly average effluent temperatures are presented in Table 3. Average temperatures vary from a minimum of 65°F in January to a maximum of 85°F in July.

Daily temperature measurements exhibited variations of up to 5°F from the monthly averages shown on Table 3.

Caustic cleanup wastes and formaldehyde sterilizing solutions are discharged. Quantities were small and did not appear to effect the biological treatment processes. The composite effluent pH varied between 5.3 to 6.8 averaging approximately 6.1. Biological processes normally operated in the neutral pH range (6.5 to 8.0).

Table 3 Monthly Average Effluent

Month	Average Temperature °F
January	65
February	66
March	68
April	71
May	73
June	80
July	85
August	84
September	80
October	74
November	73
December	66

Only limited nutrient analyses of the effluent were made. Total nitrogen concentrations of 300 to 800 ppm were indicated for the composite effluent. Nitrogen values agree with the nutrient content of yeast wastes reported in the literature.

Phosphorous concentrations are estimated in the range of 50 ppm to 100 ppm.

Unit Waste Loadings

As most of the plant's waste load is attributable to yeast production, correlations relating molasses consumption and waste loading were possible. Variations were too large, however, for the development of consistent unit loading relationships on a daily basis. The effects of daily variations were sufficiently damped, however, through the use of a weekly time scale.

The relationship between total weekly effluent flow and total weekly molasses consumption is shown on Figure 1. The slope of the relationship is indicative of the total weekly quantity of effluent attributable to yeast production, i.e. 2.26 gallons per pound of molasses consumed. The intercept indicates the weekly flow resulting from plant processes, other than those related to molasses consumption.

Weekly effluent, BOD and COD loadings were also correlated with molasses consumption during periods for which effluent samples were available. The relationship is shown in Figure 2. The data are not of sufficient accuracy to determine, by extrapolation, the load contribution from operations not associated with molasses consumption. However, unit contributions of 0.12 pounds BOD and 0.175 pounds COD per pound of molasses are considered representative in that the data have shown the contributions from miscellaneous processes are small by comparison to yeast production.

Figure 1

TOTAL WEEKLY EFFLUENT FLOW
VS
MOLASSES CONSUMPTION

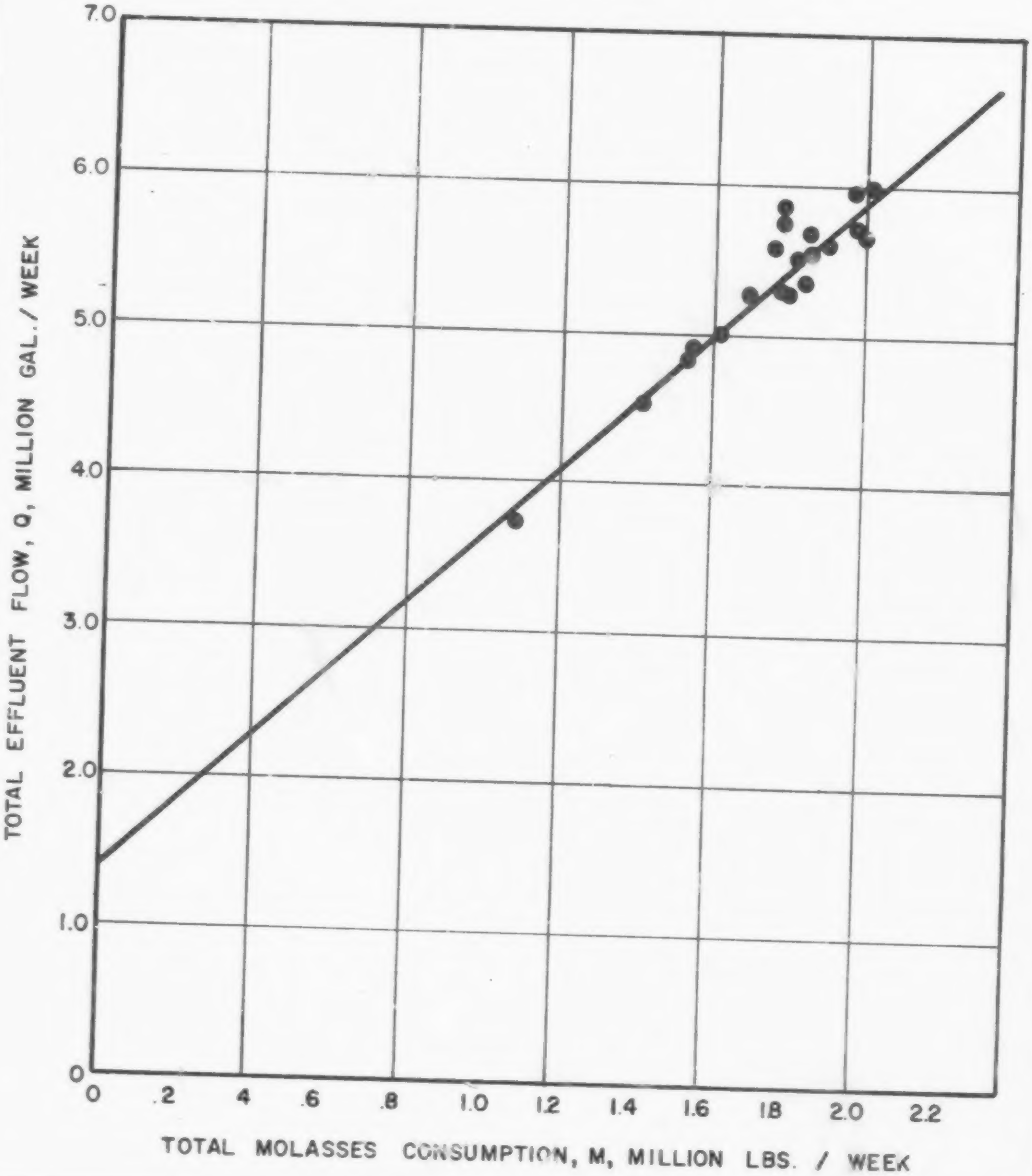
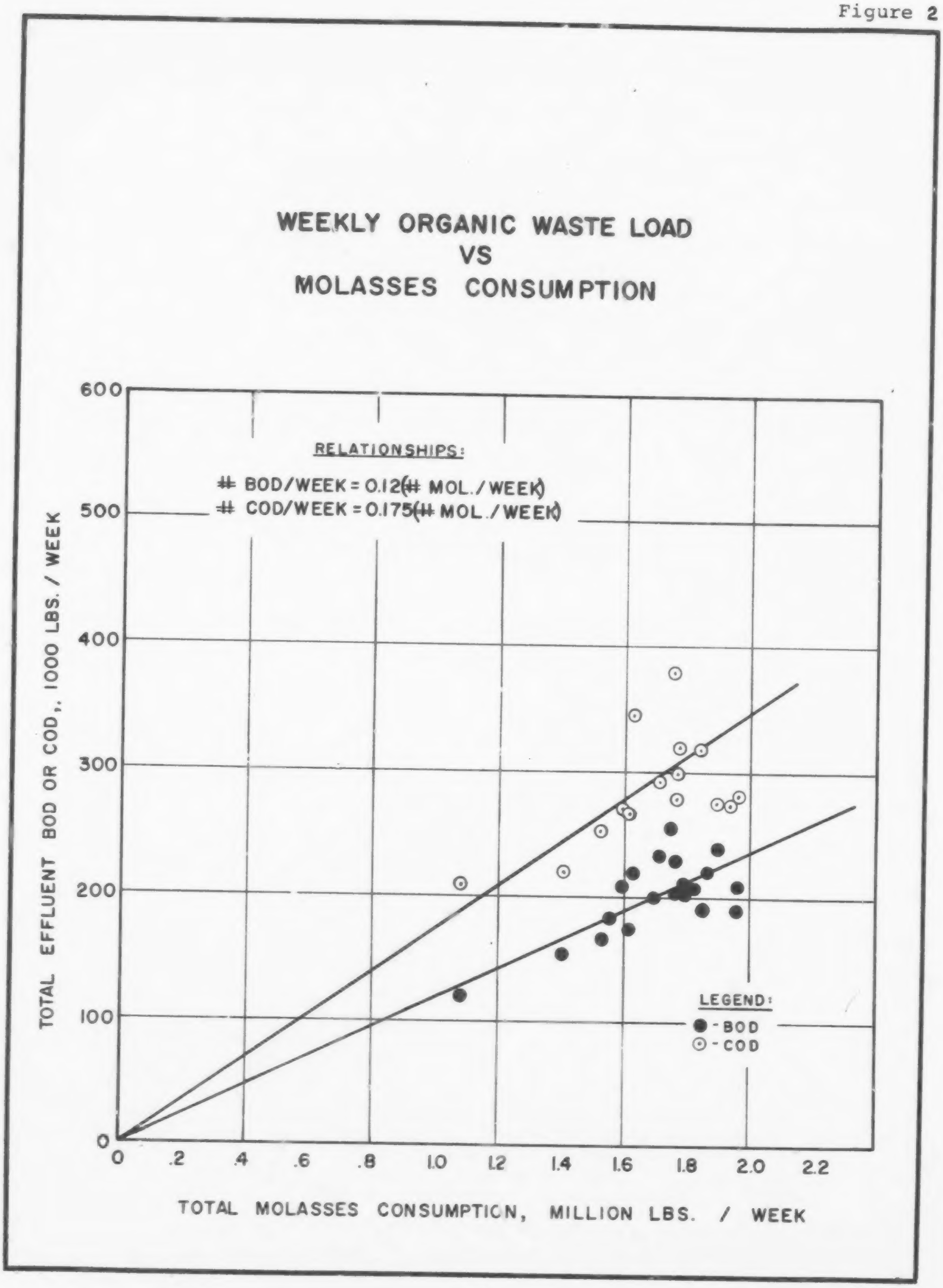


Figure 2



WEEKLY ORGANIC WASTE LOAD VS MOLASSES CONSUMPTION

PREVIOUS TREATMENT EXPERIENCE

The concentrations of dissolved organics in yeast plant effluents can exceed those of average municipal wastes by a factor of 20 or more, and present a particular problem from the treatment standpoint.

Yeast plants have traditionally located within municipal boundaries and have been served by municipal sewage treatment facilities. The resulting dilutions have obviated any difficulties in stabilizing the concentrated effluent using conventional treatment methods.

Data available from the engineering literature for yeast effluent treatment are meager and inconclusive from a standpoint of a process design. Published information generally relates to low effluent flow volumes or considers process designs whose cost and land area requirements are not generally applicable to all situations.

A small but extensive treatment facility for a similar effluent was operated in the midwest. The production facility has been taken out of operation. Treatment operations included: equalization, anaerobic digestion, trickling filtration, gravity sedimentation, chlorination and final effluent stabilization lagoons. Plant operating data were found to be meager and in conflict with check sampling performed by State regulatory engineers. Recovery and analyses of available treatment plant operating records did not yield useful information.

Pilot plant studies were undertaken by Anheuser-Busch on yeast effluents over a five year period. The effluent had a maximum concentration of about 1/2 the average value shown on Table 2. Treatment processes studied included: sedimentation, coagulation, aeration and a combination of digestion and trickling filtration. The digesters were fed from a batch holding tank at steady rates with periodic sludge return from a gravity final clarifier. Digester effluent was applied to a rock filled trickling filter followed by a final clarifier and recirculation system. Records of pilot plant operation were destroyed.

Analysis of summary information, available in the literature indicated the need for effective and continuous sludge recirculation in order to reduce digester detention times and net sludge yield. Trickling filter performance demonstrated process feasibility and indicated the advisability of applying synthetic packing materials in place of the traditional stone media.

Process design data, developed by comparatively recent university research work on continuous digestion of soluble high BOD wastes, have demonstrated the capability of achieving high BOD reductions with low sludge yields while maintaining low detention times.

The lack of suitable literature data or field experience in continuous treatment of high BOD yeast wastes required that independent pilot plant studies be undertaken.

BIOLOGICAL TREATMENT PROCESS

Compliance with treatment requirements will require BOD removals of 90 percent.

Alternative treatment methods considered include: chemical coagulation, ion exchange, reverse osmosis and biological oxidation.

The capability of processes other than bio-oxidation were evaluated and demonstrated that neither sufficient removal nor an economical process could be obtained. Biological treatment methods were determined as the treatment process of choice.

Biological treatment processes available included: anaerobic digestion, trickling filtration, activated sludge and combinations of these flow sheets.

Anaerobic Biological Treatment

The anaerobic process is similar in flow sheet to activated sludge and includes a digester, a secondary clarifier and secondary sludge recirculation. Digester contents may be heated and mixed. Digester effluent may be degassed prior to secondary clarification. Process characteristics include: the ability to treat variable and highly concentrated BOD effluents with minor operating adjustments; the ability to achieve high BOD reductions and absorb load fluctuations; a minimum production of biological sludge; minimum power consumption; and high site requirements for process tankage.

Trickling Filtration Treatment

The trickling filter process would employ towers packed with synthetic plastic media, recirculation of tower effluent and final clarification of tower mixed liquor. Process characteristics include: the ability to treat variable and highly concentrated BOD effluents with minor operating adjustments; the production of relatively low quantities of excess biological sludge; a relatively low power consumption and a minimum site requirement for process tankage.

Activated Sludge Treatment

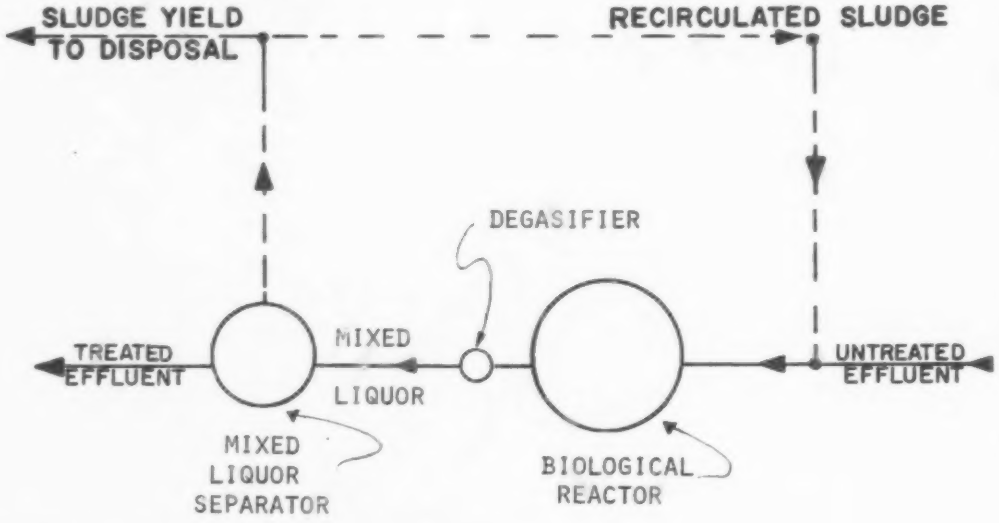
The activated sludge process would employ a totally mixed aeration tank, oxygen supply by sparged turbines aerators or by pure oxygen, secondary clarification and sludge recirculation. Process characteristics include: a need for equalization of BOD loading input, the need for special oxygenating provisions for high demand satisfaction, a maximum production of waste biological sludge, maximum power requirement and the ability to achieve highest BOD removals. Site requirements for process tankage are intermediate between other processes.

A flow sheet schematic for biological processes is shown on Figure 3.

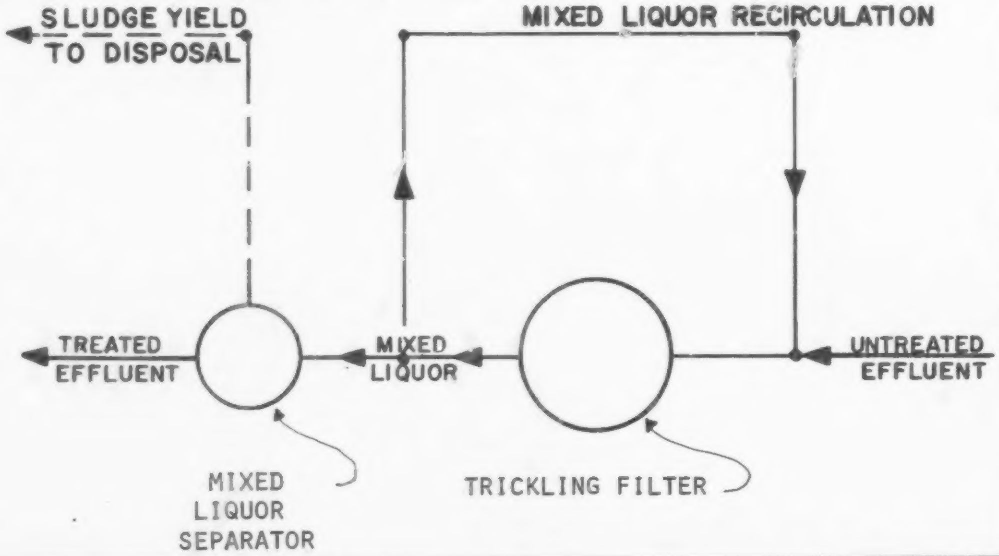
Figure 3

SCHEMATIC FLOW SHEET — BIOLOGICAL TREATMENT YEAST PLANT EFFLUENTS

ANAEROBIC & ACTIVATED SLUDGE PROCESS SCHEMATIC



TRICKLING FILTRATION PROCESS SCHEMATIC



Anaerobic Digestion Process Design

The decomposition of soluble organics through anaerobic digestion proceeds as a series of simultaneous steps. These reactions may be conveniently expressed in two reactions as follows:

$$\text{BOD}+\text{Organisms}\rightarrow\underset{\text{Acids}}{\text{Volatile}} + \underset{\text{Organisms}}{\text{New}} + \underset{(C_aCO_3)}{\text{Alkalinity}} + \underset{(CH_4+CO_2)}{\text{Gas}} \quad \ldots.(1)$$

$$\text{Organisms}+\underset{\text{Acids}}{\text{Volatile}}\rightarrow\underset{\text{Acids}}{\text{Volatile}}+\underset{(C_aCO_3)}{\text{Alkalinity}} + \underset{(CH_4+CO_2)}{\text{Gas}} \quad \ldots.(2)$$

The conversion of complex organics to volatile acids is accompanied by high organism growth rates and may be accomplished at low detention times. As organism or detention time increases, volatile acids are metabolized to stable end products (gases and alkalinity) and the organisms undergo self-decomposition. This self-decomposition is termed endogenous respiration.

Increased organism age results in increased endogenation and increased gas yields. Both reactions are dependent upon: pH, temperature, mixing, BOD concentration, and organism (sludge) concentration.

BOD removal may either be direct by conversion of organic matter to alkalinity and gas or indirect by conversion of organic matter to organisms. Separation of these organisms from the digester effluent is required to complete the removal process.

In anaerobic systems without sludge recirculation, the organism age is low and BOD removal is largely indirect, accompanied by high sludge yields. In recirculated systems, sludge age is high and BOD removal is mainly direct and accompanied by low net sludge production.

Analysis of the anaerobic process required a definition of the following components:

1. BOD removal
2. Sludge production
3. Gas production
4. Solid-liquid separation and sludge compaction

The development of process design models for selected components is summarized below.

BOD Removal Model

BOD removal is obtained by simultaneous operation of two biological pathways. In the presence of organisms, BOD is initially converted to organic acids which are then processed into the end products of: sludge, methane, and carbon dioxide. The interaction of both pathways determines the rate and extent of BOD removal, biological sludge production and gas generation.

Definition of the hydraulic conditions in the digester and a selection of a suitable kinetic law for the treatment reactions were used to develop a process design.

Data correlation was achieved using a model for a totally mixed, digester operating under the kenetics of a first order reaction.

The first order reaction model may be expressed in a number of forms. Expressions of particular interest relate the efficiency of BOD removal and the velocity of BOD removal to combinations of the remaining process parameters. The formulation for efficiency is most convenient for design computations and expresses removal as a function of the biological rate constant and the product of mixed liquor sludge concentration and digester detention time as follows:

$$E_R = \frac{(k')\ (S_D\ .\ T_D)}{(k')\ (S_D\ .\ T_D) + 1} \quad \dots\dots\dots\dots\dots\dots\dots \quad (1)$$

Where: E_R = BOD removal efficiency expressed as a fraction

k' = a specific biological rate constant expressed in units of 1/ppm x days

S_D = digester mixed liquor sludge concentration expressed in units of ppm

T_D = digester detention time, in days, for raw waste flow

For a given value of (k'), specifically for the effluent and temperature of operation, the solids time product $(S_D.T_D)$ required to obtain a selected BOD removal (E_R) may be determined. Detention time is determined by selection of a mixed liquor solids concentration. Detention time is minimum for that value of S_D which represents a maximum operating value.

Equation (1) may be represented as a linear relationship on Cartesian coordinates yielding a graphical procedure for model verification and determination of the rate constant k'. The linear relationship is obtained by plotting $1/E_R$ as ordinate versus $(1/S_DT_D)$.

While useful for design computation, the efficiency relationship has limited utility in the analysis of pilot plant data when the process is operating within a narrow range of efficiencies. (S_DT_D) is an easily measurable parameter and represents a major pilot plant operating parameter of wide variation. Efficiency on the other hand usually experiences a less dramatic change during pilot plant investigations, especially when excess sludge wasting is held to a minimum. This was the case in certain series of these investigations where E_R varied from 80 to 95 percent while $(S_D\ .\ T_D)$ varied from 3000 to 14,000 ppm/day. For the analysis of data of this type equation (1) can be rearranged to incorporate less sensitive process parameters as follows:

$$\frac{L_a}{U_L} = \frac{1}{k'} + S_D T_D \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \quad (2)$$

where: L_a = BOD applied ppm (adjusted, as necessary, for changes in reactor BOD storage).

U_L = BOD removal velocity, # BOD/# Sludge/day.

k' = specific biological constant, 1/ppm x days

The BOD removal velocity U_L may be otherwise stated as the pounds of BOD removed per day, per pound of sludge solids.

Equation (2) relates the concentration of the BOD applied and the velocity of BOD removal to the environment of the digester as described by the solids-time product. The relationship may be expressed in a linear format on Cartesian coordinates by plotting the ratio (L_a/U_L), as ordinate, versus the solids-time product $(S_D \cdot T_D)$. The slope of the correlation is 1.0 and the intercept $(1/k')$.

Data obtained in the study were analyzed in accordance with these forms of a first order kinetic model.

Temperature Effects on BOD Removal

The value of (k') increases with increasing temperature. Correlation of temperature effects by the Arrhenius relationship yields the following statement:

$$(k')_t = (k')_{35^\circ} (\theta)^{t-35} \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \quad (3)$$

Where: $(k')_t$ = rate constant at temperature (t)

$(k')_{35^\circ}$ = rate constant at reference temperature of 35°C

θ = a temperature rate constant at 1.07 for anaerobic digestion

t = digester temperature in °C

The effects of temperature can be significant. For example, a drop in digester temperature from 95°F to 75°F (35°C to 23.8°C) can require a 100 percent increase in digester detention time for the maintenance of equivalent BOD removals.

BOD Removal Rate Constants

Anaerobic treatment data are divided into the following series:

Series #1 - Non-recirculated digestion

Series #2 - Sludge recirculated digestion

Experimental equipment for high and low temperature work is shown on Figure 4.

The BOD removal kinetics observed in each series are presented graphically in Figures 5 and 6. Data abstracted from studies reported in the literature on the subject have been included in Figure 5 for comparison purposes.

The data show that significant increases in removal rates can be realized through the recirculation of digester effluent solids. Reductions in digester temperatures can also cause significant reductions in removal rates. Failure of the digester process occurred at mixed liquor temperatures of approximately 55°F.

Significant reductions in biological rates at low temperatures, coupled with the creation of odor problems as temperatures are reduced, indicate that the process of choice under this series would incorporate elevated digester mixed liquor temperatures.

Sludge Production Model

A material balance across a digestion unit may be written for sludge production in a manner comparable to that used for BOD removal.

Calculation of net sludge production over short balance period is significiantly affected by solids accumulations within the reactor. The effect of digester accumulations is pronounced in anaerobic systems in which net sludge yields are low. Corrections for changes in storage or operation for prolonged periods was necessary under these conditions. Pilot plant data were analyzed in accordance with these requirements.

Reactions 1 and 2 depict the role of biological cells in the anaerobic decomposition of organics. The organisms, initially produced through the metabolic utilization of organics eventually undergo auto-gasification or endogenous respiration as sludge age increases.

The net sludge production from the process is the difference between the growth of new cells and endogenous respiration of the digester population. Both reactions occur simultaneously and are related to BOD removal as follows:

$$U_s = Y_s U_L - U'_s \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

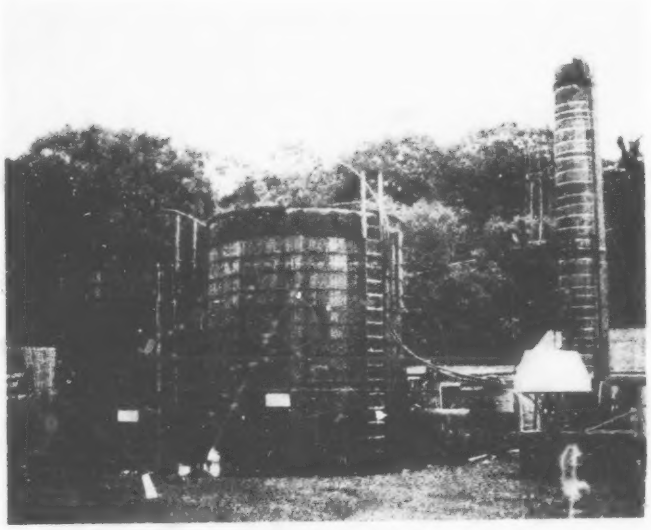
Where: U_s = the velocity of sludge production convenient units are #sludge produced/#sludge present/day.

Y_s = the gross metabolic organism yield, #solids/# BOD_r

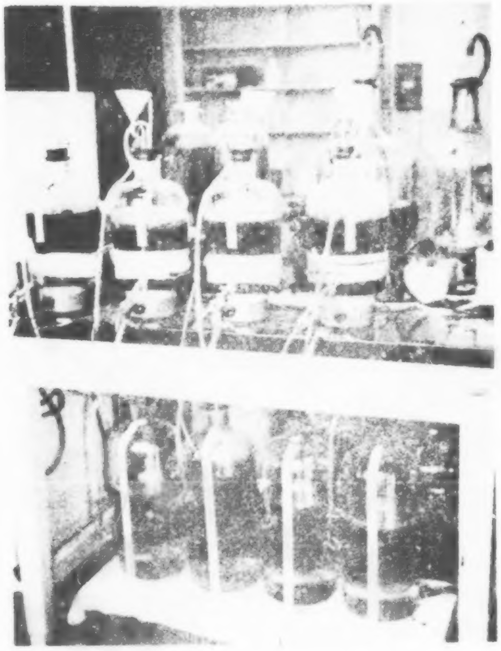
U_L = the velocity of BOD removal - convenient units are #BOD removed/#sludge present/day.

U'_s = the velocity of sludge endogenation, convenient units are #sludge endogenated/#sludge present/day.

Figure 4



Main Pilot Plant - 21,000 Gallon
Digester and Surfpac Trickling Filter

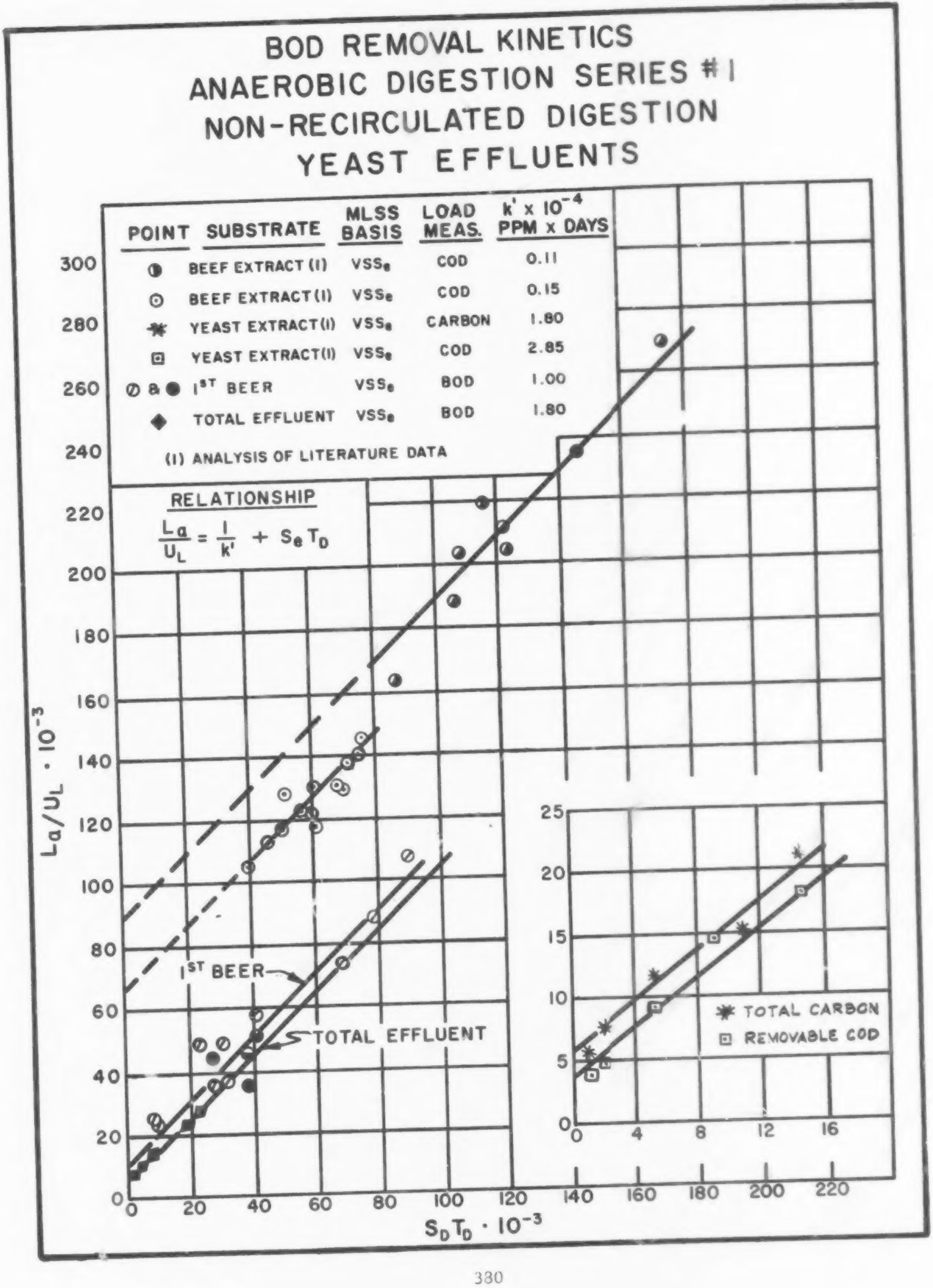


View of Bench Scale 3 Liter
Digesters and Gas Collector

50 Gallon Pilot Plant Solonoid Feed,
Mechanical Mixers Effluent Container
and Settling Tank

General View of Waste
Treatment Laboratory

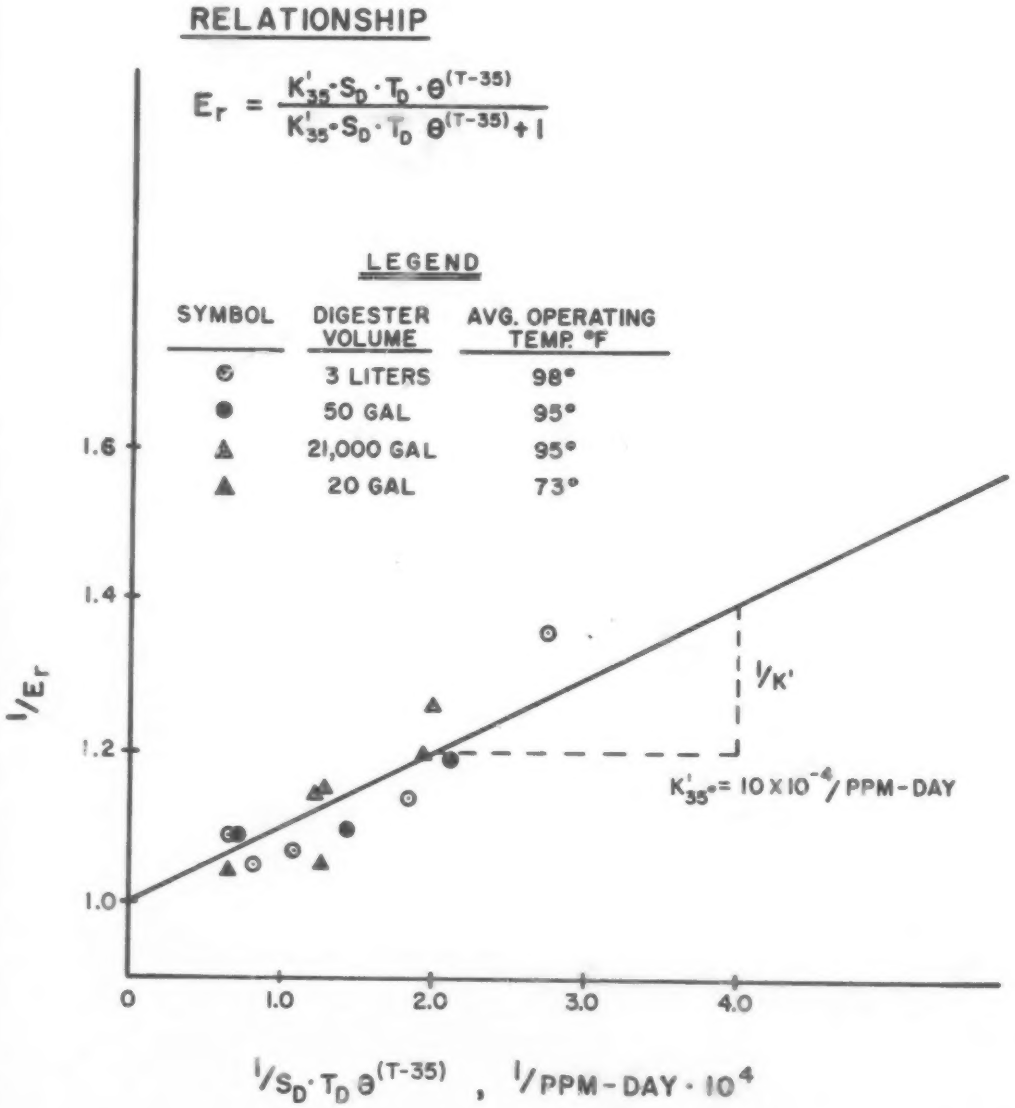
FIGURE 5



BOD REMOVAL KINETICS
ANAEROBIC DIGESTION SERIES #1
NON-RECIRCULATED DIGESTION
YEAST EFFLUENTS

FIGURE 6

BOD REMOVAL KINETICS
ANAEROBIC DIGESTION SERIES #2
SLUDGE RECIRCULATED DIGESTION
YEAST EFFLUENT



RELATIONSHIP

$$E_r = \frac{K'_{35} \cdot S_D \cdot T_D \cdot \theta^{(T-35)}}{K'_{35} \cdot S_D \cdot T_D \, \theta^{(T-35)} + 1}$$

LEGEND

SYMBOL	DIGESTER VOLUME	AVG. OPERATING TEMP. °F
⊙	3 LITERS	98°
●	50 GAL	95°
▲	21,000 GAL	95°
▲	20 GAL	73°

Equation 4 is employed to determine values for the sludge production constants Y_s and U_s' by graphical analysis of sludge production and BOD removal measurements. The relationship is linear on Cartesian coordinates when sludge production (U_S) is plotted, versus BOD removal (U_L). Sludge production constants Y_s and U_s' are employed to determine: the net sludge production from the process, the digester environment required for minimum sludge production and the digester environment for maximum BOD removal.

Equation (4) may be rearranged to yield a relationship for net sludge yield per unit of BOD removed as follows:

$$\frac{\Delta S}{L_r} = Y_s - \frac{U_s'}{U_L} \quad \ldots\ldots\ldots\ldots \quad (5)$$

The equation illustrates the reduction in unit sludge production as BOD removal velocity is reduced. The BOD removal velocity or zero sludge production, i.e. $\Delta S/L_r = 0$, is determined as:

$$(U_L) \text{ min} = \frac{U_s'}{Y_S} \quad \ldots\ldots\ldots\ldots \quad (6)$$

Design for operation at (U_L) minimum will provide the minimum sludge for disposal.

Table 4 summarized the gross metabolic yield (Y_s) and endogenous respiration velocity (U_s') observed.

Table 4 Summary - Biological Sludge Production Parameters Anaerobic Digestion

Series	Effluent Flowsheet	Digester Temp. (F°)	Y_s (#/#)	U_s' (#/#/Day)
1	Non-Recirculated			
	a. Yeast Effluent	98	.30	0
	b. Beef Extract (1)	98	.06 - .10	0
2	Sludge Recirculated			
	Yeast Effluent	98	.45	.25
	Yeast Effluent	73	.39	.026

(1) Literature Data

The sludge yield of high temperature sludge recirculated anaerobic systems is considerably lower than comparable aerobic systems, e.g. an overall sludge yield of 0.075 #/# of BOD removed can be anticipated from the 95°F, sludge recirculated digestion. Sludge yields are increased at lower temperatures through the reduction of the endogenous velocity from 0.25 at 95° to 0.03 at 73°F.

Minimum Sludge Production

Minimum sludge production occurs at the point at which sludge production balances sludge endogenation.

Design conditions for operation at zero solids yield can be approximated by a combination of Equations 2 and 4 to relate the solids time product at balanced conditions with sludge production constants and the BOD removal rate constant as follows:

$$(S_D T_D)_B = \frac{(Y_s)}{(U_s^{\prime})} (L_a) - \frac{1}{k^{\prime}} \quad \ldots\ldots\ldots\ldots\ldots \quad (7)$$

Where: $(S_D T_D)_B$ = the solids time product in ppm x days at which biological sludge production is balanced by sludge endogenation.

L_a = BOD concentration applied to the digester in ppm.

The need to increase the value of $(S_D T_D)$ in proportion to increases in the BOD concentration of the waste applied to the digester (L_a) is shown by Equation 7.

At a solids time products below the indicated balance point value, BOD reductions are decreased and net production of biological sludge is evidenced.

Table 5 summarizes the balance point values of digester solids time products for the series of effluents studied.

Table 5 Anaerobic Digestion Solids Time Products Required For Minimum Sludge Production

Series		Temperature °F	$(S_D T_D)_B$ In ppm x days
2	Sludge Recirculated Digester		
	a. Yeast Effluent	95	7,500
	b. Yeast Effluent	73	68,500

Average data indicated that 30 percent of raw waste solids were gasified during digestion at solids time products above 10,000 ppm x days.

Maximum BOD Removal

For a sludge recirculated digester, at a given temperature, maximum BOD removal will be obtained at balance point operation. That is, at a solids time product for which sludge production balances sludge endogenation. At this point, the BOD concentration of the mixed liquor has been reduced to the level for which the rate of BOD removal is sufficient for the generation of new sludge in the amount required to balance sludge loss from the total mass of mixed liquor solids.

Utilization of the relationship between BOD removal velocity and BOD concentration in a first order reaction, allows determination of the minimum operating BOD as follows:

$$(L_e)\ \text{min} = \frac{U'_e}{Y_s\ .\ k'} \qquad (8)$$

Process design Equation 7 and 8 allow determination of maximum process performance from measurements of: sludge production and endogenation constants and the biological rate constant for BOD removal.

Table 6 summarizes the minimum BOD concentrations considered obtainable from application of the anaerobic process to study effluents.

Table 6 Yeast Effluents: Minimum Soluble BOD Concentrations from Anaerobic Treatment Using Sludge Recirculation

Series	Effluent	Temperature °F	(L_e) Min. ppm
2	Yeast Effluent	95	555
	Yeast Effluent	73	170

Solids-Liquid Separation & Sludge Compaction

Mixed liquor solids control, upon which the sludge recirculated anaerobic digestion systems depends, is inturn dependent on the solids-liquid separation following the digester.

Separation processes include gravity sedimentation and flotation. Separation characteristics may often be enhanced by the addition of flocculant aids such as polyelectrolytes.

Bench scale settling and compaction studies were performed in liter cylinders equipped with stirring rakes under controlled temperature conditions.

An extensive series of laboratory experiments evaluating the effects of chemical addition in the form of both primary and secondary coagulants on sludge sedimentation characteristics were conducted. Test results were negative.

Settling characteristics of digester solids vary with temperature, concentration and the extent of gas entrainment. Sludge leaving the digester may contain a large amount of entrapped digestion gases. The degree of entrainment is a function of digester mixing and mixed liquor solids concentration. Degasification of the sludge through the application of vacuum has been shown to substantially increase sedimentation characteristics.

Effluent suspended solids concentrations averaging 500-600 ppm were experienced in pilot plants operating without sludge degasification. Sludge degasification would be expected to decrease clarifier effluent suspended solids concentrations to below 200 ppm.

Laboratory experiments in liter cylinders were conducted on degasified and undegasified pilot plant sludges.

As the final clarifier will function both as a clarifier and thickener, clarifier loading values in terms of gallons per day/square foot and lbs solids/day/ft^2. Normal municipal practice is to size clarifiers for 800 gpd/ft^2 and thickeners at 10 ppd/ft^2. Clarifier overflow rates of less than 300 gpd/ft^2 were indicated in the operation without degasification. A sharp decrease in overflow rate was experienced as clarifier influent solids exceed 5000 ppm.

Design criteria established through these analyses are summarized below:

1. Thickening rates are approximately doubled by sludge degasification.

2. Organisms continue to produce gas in the clarifier. This secondary gasification may cause eventual solids flotation and contribute to solids loss. Maximum allowable clarifier detention times to prevent sludge flotation should not be exceeded.

3. Consistant operation of a gravity separator will require the installation of sludge degasification.

4. Sludge degasification will be required to attain high suspended solids removal efficiencies.

5. The critical clarifier influent concentration beyond which hindered settling occurs throughout the clarifier and overflow rates severely reduced was indicated at 5200 ppm. Higher mixed liquor concentrations will require recycle of clarified effluent to the clarifier feed well to maintain clarifier performance.

TRICKLING FILTRATION PERFORMANCE

The classic trickling filter comprises a bed of stone media over which attached biological slime growths develop. Removal of BOD is obtained by aerobic processes at the slime surface and by anaerobic processes within the slime interior.

Prior to the introduction of synthetic media for trickling filters, 1-1/2 to 3" crushed stone or slag was universely employed as a packing material. Filter sizing was developed from municipal practice and utilized organic loading expressed in #BOD/cf/day as a guide for design. Because of the media plugging which resulted from application of concentrated wastes, such as yeast effluent, operating experience for these effluents are limited.

Packed tower modifications to the trickling filter introduced plastic geometric packing media to obtain increased surface area and porosity. Current practice employs a lattice structure similar to an egg carton insert. BOD removal performance is related to process parameters using an analytical model descriptive of the biological relation observed and the hydraulics of the reactors.

Numerous design relationships have been developed for specific applications of synthetic media. Application of these relationships failed to correlate pilot data or literature data for similarly concentrated wastes in a consistent manner. Wide variations in tower volume for a specified BOD removal were obtained as different formulations were applied. Determination of required tower volume by accumulation of consistent operating data for major design variables, could not be employed because of the time limitations imposed on study execution. An independent basis of design was developed and confirmed for use in analyzing study data and in extrapolating design requirements for filter application.

Experimental Procedures

The packed tower trickling filtration process was studied for treatment of yeast effluent alone and for combinations of yeast effluent and municipal sewage. Both waste flow conditions were found amenable to treatment via bio-filtration.

Experimental studies utilized data from two pilot plant systems:

1. A Surfpac media pilot plant

2. A laboratory simulated trickling filter

The Dow pilot plant was installed at the yeast plant for independent effluent treatment studies. As the need arose for evaluation of the trickling filtration process for combinations of the industrial waste and sewage, it became apparent that the transportation of large amounts of sewage to the pilot plant for treatment studies would be too time consuming and costly. Pilot plant operating flexibility under these conditions would be curtailed.

A small scale laboratory trickling filter was constructed to provide a high degree of flexibility. The laboratory system utilized the geometry of an inclined plane over which the effluents were trickled. The system allowed the observation of slime growth and BOD removal characteristics.

Features of the Surfpac pilot plant and the QL&M laboratory systems are presented in Figures 7 and 8.

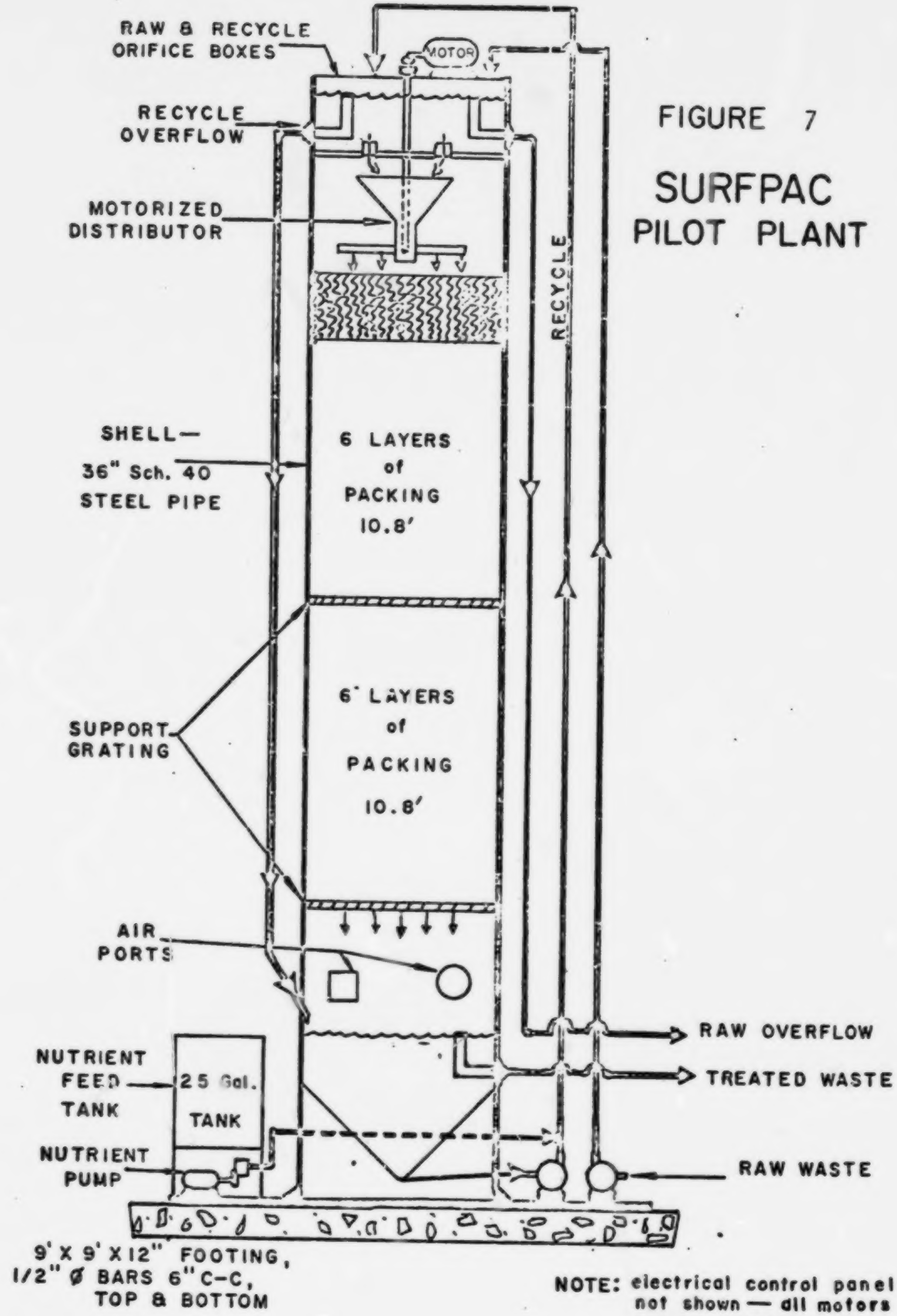
General descriptions of the operation of each of the systems follows:

1. Surfpac Pilot Plant

The 3' diameter, 21.5' high pilot plant was mounted on a concrete platform in an outdoor area designated for waste treatment pilot plants at the yeast plant. Pilot plant feed and recycle rates were controlled by constant head orifice boxes located at the top of the unit. The unit was insulated and contained provision for the installation of a blower for supplementary air supply to the media. Modifications to the manufacturer's original design included the installation of a sump temperature control system and a small metering pump for the maintenance of feed and recycle

FIGURE 7

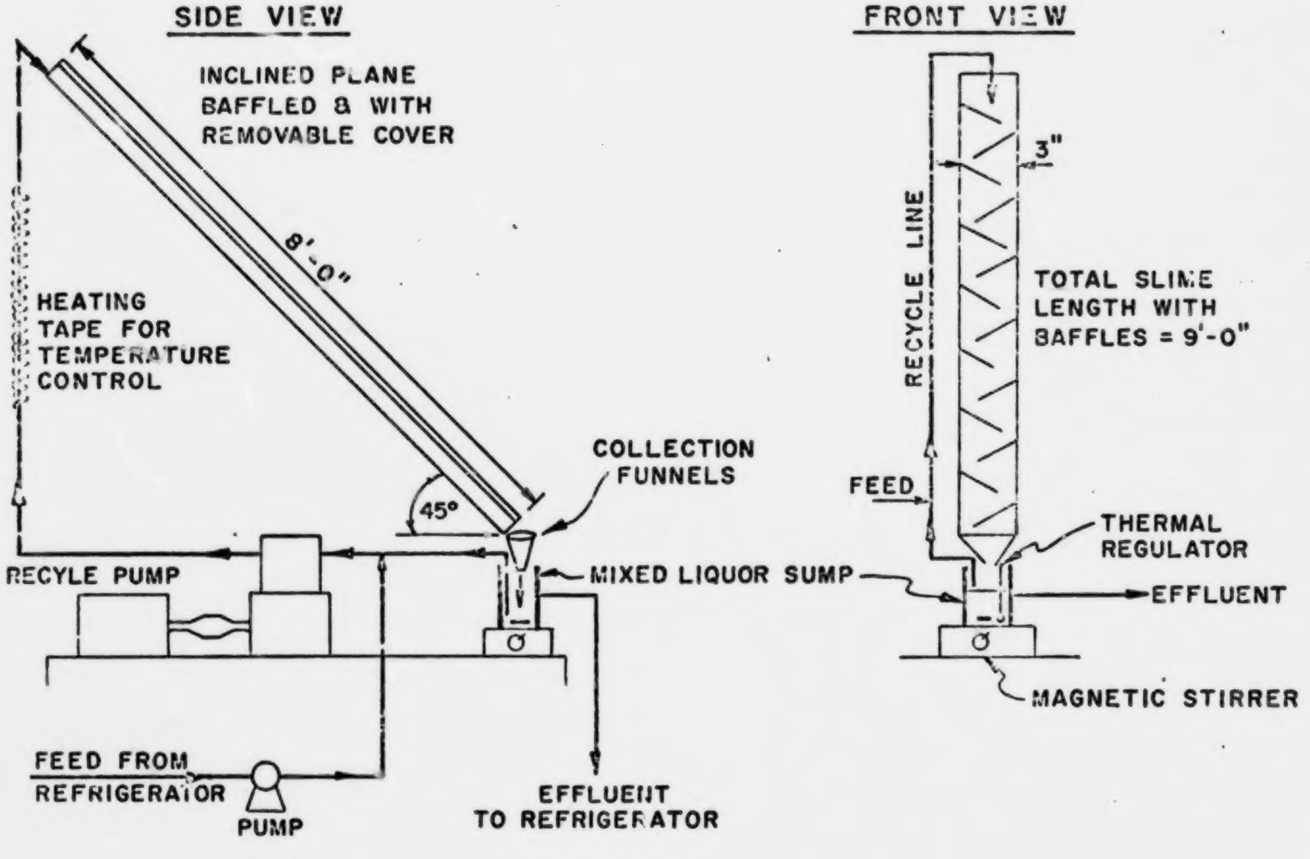
SURFPAC
PILOT PLANT


RAW & RECYCLE ORIFICE BOXES
MOTOR
RECYCLE OVERFLOW
MOTORIZED DISTRIBUTOR
RECYCLE
SHELL— 36" Sch. 40 STEEL PIPE
6 LAYERS of PACKING 10.8'
6 LAYERS of PACKING 10.8'
SUPPORT GRATING
AIR PORTS
RAW OVERFLOW
TREATED WASTE
NUTRIENT FEED TANK
25 Gal. TANK
NUTRIENT PUMP
RAW WASTE
9' X 9' X 12" FOOTING, 1/2" Ø BARS 6" C-C, TOP & BOTTOM

NOTE: electrical control panel not shown — all motors require 110/220 volts

FIGURE 8

TYPICAL LABORATORY SIMULATED TRICKLING FILTER PLANE



flows too low for accurate orifice control. The pilot plant studies spanned 2 series. Series 1 investigated the use of trickling filtration as a polishing process in series with a non-recirculated anaerobic digester. Series 2 investigaed bio-filtration as a single process. The pilot plant was fed four days to conform to the normal yeast production schedule. Recycle from the pilot plant sump kept the biological slimes wet and viable during off production weekend periods.

Operation of the pilot plant provided BOD removal data for the development of a design model incorporating the effects of waste concentration and hydraulic application velocity. Prototype design criteria such as gpm/ft^2, the minimum application velocity required to keep the media surface wet, and the effect of high recycle ratios on BOD removal were evaluated. The pilot plant operated over a wide range of organic and hydraulic loading conditions.

Operating experience at low temperatures and with supplementation of tower air supplies by an external blower were obtained.

Pilot plant experience demonstrated that approximately 3 weeks of operation were required prior to attaining a representative material balance for BOD removal and slime growth at any given loading condition. Because of these time requirements experimental verification could not be achieved for all potential design conditions.

2. Laboratory Trickling Filter System

The simulated laboratory trickling filter system was constructed to provide flexibility in waste loading variation and system operation. Daily feed volumes were small enough to allow the entire filter effluent to be stored in a refrigerator for preservation during feeding and collection. Slime surfaces were large enough to provide a wide range of BOD reductions and sludge yields.

The laboratory filters were rectangular plane surfaces set at a 45° incline. The 8 foot length of each filter was baffled to extend the effective slime length to approximately 9 feet. The total surface area of slime available per unit was approximately 1.1 sq. ft.

Plane recirculation ratios, as well as BOD and hydraulic loadings were scaled to approximate prototype conditions.

BOD Removal Model For Pretreatment

BOD removals up to approximately 70 percent in flow over an inclined plane or through a full scale packed tower were shown to follow a zero order reaction and to be related as follows:

Inclined plane: $E = k / (OL)$ . . . . (9)

Surfpac Packed Tower: $E = K / (OL)$ . . . .(10)

Where: k = Specific biological rate constant in units of ppm x gpm/SF or pounds/day/SF

K = Packed tower rate constant including effects of media specific surface. Constant expressed in units of ppm x gpm/CF or pounds/day/CF

OL = Organic loading as unit weight of untreated BOD per unit area of slime area or filter volume

E = Efficiency of BOD removal

Influence of Temperature

The effect of temperature on reaction rate is introduced using the Arrhenius relationship.

$k'_t = k'_{20}\theta^{\Delta T}$ . . . .(11)

Where: k'_t = reaction constant at temperature t

k'_{20} = reaction constant at standard temperature, 20°C

ΔT = reaction temperature differential °C-20

θ = constant, usually taken as 1.035

Graphical techniques used in correlating data for plane and tower performance are illustrated on Figure 9.

BOD Removal Performance

During Series #1, the Surfpac pilot plant was not equipped with any method of temperature control, as supplied by the manufacturer. The steam operated temperature control system, installed in the field to serve as an interim control measure, was incapable of maintaining tower temperatures within a tolerance of ± 5°F. Operating instability caused by temperature variations and by other mechanical difficulties are incorporated in the data.

During Series #2, an automatic temperature control system was installed. Temperature variation was reduced to a range of ±2°F.

Yeast effluent may vary in strength from 1000 to 15,000 ppm BOD. During the operation of the pilot plants, facilities which partially equalized 1st beer were in use. Raw waste variations were reduced to a range of 2500 to 8000 ppm.

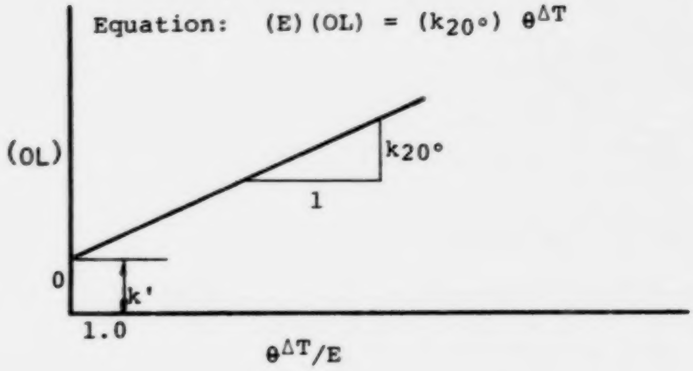
Organic loadings fluctuated as much as 300 percent for any given hydraulic loading. BOD removal varied from 25 to 85 percent during these studies.

Figure 9

ZERO ORDER MODEL CORRELATIONS

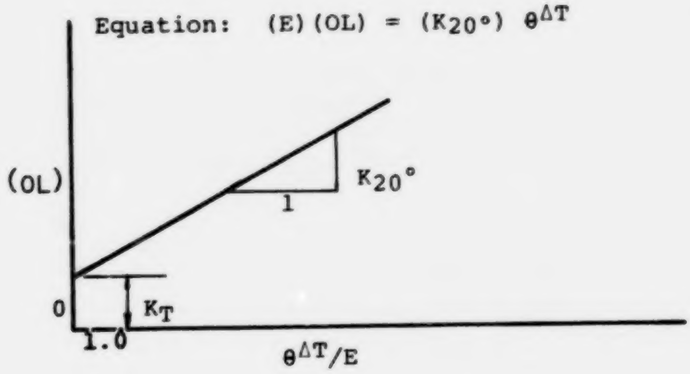
ANALYSIS OF SLIMED PLANE

Equation: $(E)(OL) = (k_{20°})\ \theta^{\Delta T}$



ANALYSIS OF PACKED TOWER

Equation: $(E)(OL) = (K_{20°})\ \theta^{\Delta T}$



Analyses of plane and tower operating data, using the zero order BOD removal model, are shown on Figure 10.

The laboratory plane, operating under more controlled conditions than the pilot plant, was amenable to process design modelling for BOD removals up to approximately 70 percent. A zero order reaction fitted the operating data reasonably well. Performance above 70 percent removal while attainable was not amenable to process modelling using any of the normal methods.

Pilot plant data were widely scattered but were described best by a zero order model.

For comparison purposes, laboratory plane data were scaled up to conform to the packing used in the pilot plant. Scaled up computation of removals versus organic loading are shown with pilot performance.

Organic loading is expressed in units of ppm x gpm/CF for pilot plant and laboratory data. Pilot plant data are converted to pounds/day/1000 CF by multiplication by 12.0. Model prediction are valid for design for loadings in excess of 200 #/day/1000 CF and removals less than 70 percent.

Sludge Production and Effluent Settleability

During Series #1, the tower feed system, consisting of non-recirculated digester effluent, was high in suspended solids content, ranging from 1500 ppm to 2500 ppm. This extremely high influent suspended solids concentration served to mask sludge production data. Series #2 data showed variations of from 0.1 to over 1.0 lb. suspended solids per pound of BOD removed in net biological sludge yield, depending on filter BOD removal efficiency and sloughing conditions.

Net biological sludge yields were observed and measured more closely in the laboratory.

While correlations based upon the combination of metabolic yield and endogenous respiration rates were not attempted, a net solids yield of approximately 0.3 pounds of dry solids per pound of soluble BOD removal is anticipated for a plant achieving 80 percent BOD removal.

Sedimentation of the trickling filter effluents reduced suspended solids concentrations to under 50 ppm. Overflow rates ranging from 600 to 800 gpd/ft^2 are anticipated for secondary clarifiers.

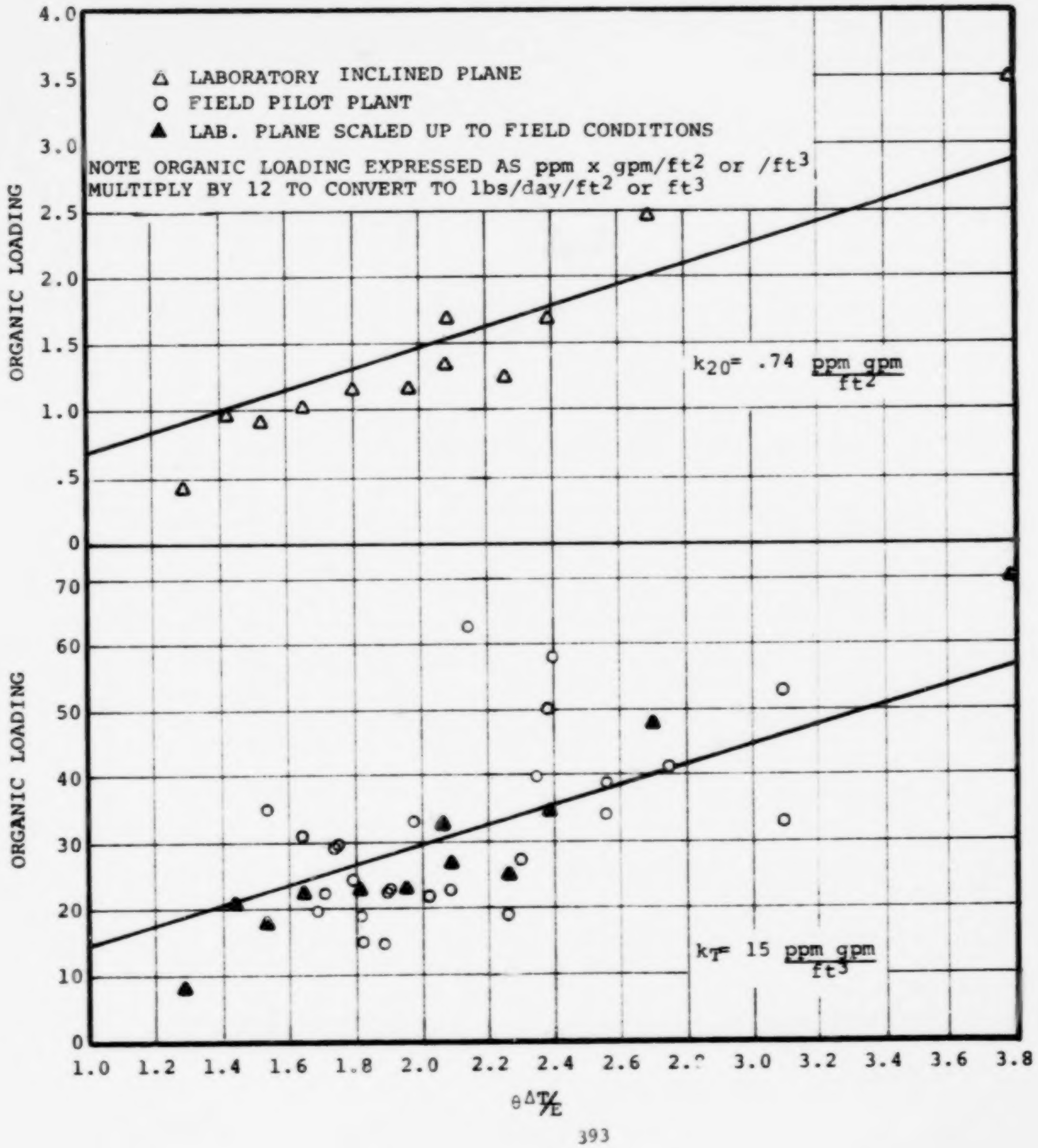
Nutrient Requirements

Pilot plant studies showed that sufficient nutrient nitrogen and phosphorous are available in combination of yeast effluent and sewage to sustain bio-oxidation at a high level.

During Series #1 of the Surfpac pilot plant operation the available nutrients in the yeast effluent were substantially reduced by anaerobic

FIGURE 10

ANALYSIS OF TRICKLING FILTRATION
YEAST WASTE



pretreatment. Nutrient supplement was utilized to insure consistent performance. Nutrient supplementation during Series #2, produced no substantial change in BOD removals.

Parallel laboratory planes run with and without nutrient supplementation on yeast wastes mixed with various amounts of sewage showed no substantial differences in BOD removals.

ACTIVATED SLUDGE TREATMENT

The activated sludge process was evaluated for treatment of combinations at yeast effluents and municipal sewage. The process was considered both for utilization as a single treatment process and also for use in series with other biological processes.

Experimental Procedures

Batch-type investigations were used as the principal source of process design data. A batch analysis refers to the instantaneous loading of effluent into a reactor and the observation of the variation of system parameters with time.

Sludge was continuously acclimated for batch reactor activated sludge seed. The system employed is shown in Figure 11. Sludge generators were fed at the rate of 0.1 lb of BOD per pound of suspended solids. An internal settling compartment provided continuous sludge recycle within the generators. A minimum acclimation period of 10-15 mixed liquor turnovers was used for all effluents. When acclimation was completed, the sludges were sacrificed for BOD removal, settling and thickening investigations.

A total of five effluents were investigated in the activated sludge studies. These included various blends of yeast effluents and sewage and alternative forms of biological pretreatment.

The effect of packed tower bio-filtration pretreatment of a combined effluent on activated sludge performance was studied in Series #1. This process is generally considered efficient from the standpoint of cost per pound of BOD removal when employed for pretreatment. The pretreated effluent was generated from the laboratory trickling filter plane.

Series #2 evaluated the effects of anaerobic pretreatment.

Series #3 and #4 utilized combined effluents without pretreatment of two dilutions with domestic sewage: a 1:3 and a 1:5.5 dilution (yeast flow to sewage flow).

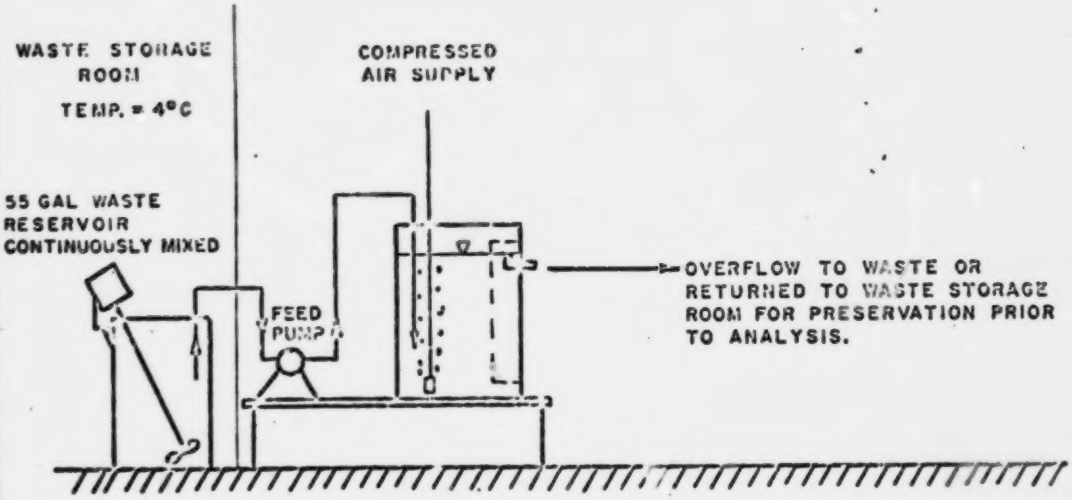
Characteristics of the batch removal studies are presented in Table 7.

Prototype design criteria required the verification of operating data for a range of operating conditions. Operating parameters include: aerator mixed liquor solids concentrations, aerator BOD loading and detention time, temperature, oxygen consumption rates, and sludge production levels.

FIGURE 11

CONTINUOUS ACTIVATED SLUDGE ACCLIMATION SYSTEM

FLOW SCHEMATIC


WASTE STORAGE ROOM
TEMP. = 4°C
55 GAL WASTE RESERVOIR CONTINUOUSLY MIXED
COMPRESSED AIR SUPPLY
FEED PUMP
OVERFLOW TO WASTE OR RETURNED TO WASTE STORAGE ROOM FOR PRESERVATION PRIOR TO ANALYSIS.

REACTOR DETAIL

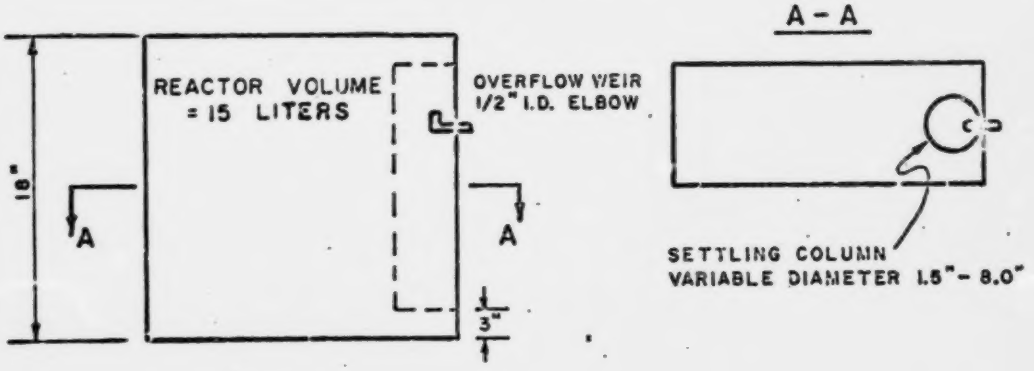

A - A
REACTOR VOLUME = 15 LITERS
OVERFLOW WEIR 1/2" I.D. ELBOW
18"
A
A
3"
SETTLING COLUMN VARIABLE DIAMETER 1.5" - 8.0"

Table 7 **Yeast Effluents: Characteristics of Activated Sludge Batch Runs**

Characteristics	Series Number			
	1	2	3	4
Number of Runs per series	3	3	3	2
Volume of Reactors, liters	10	10	10	10
Length of Runs, hours	24	24	24	24
Temperature of Runs, °C	20	20	20	20
Mixed Liquor Suspended Solids, ppm	2,400-3,340	1,440-3,000	2,100-5,800	2,500-4,600
Initial Soluble BOD, ppm	360-418	146-186	600-1,010	238-257
Soluble BOD, ppm After 24 hours Aeration	25-32	22-25	14-82	11-26
Average Oxygen Uptake Rate during first 4 hours, ppm/hr.	61-94	47-82	62-107	57-76

Basis of Analysis

BOD removal in the activated sludge process is dependent upon both the metabolic activity of the mixed liquor solids and the mixing characteristics of the aeration tank.

Analytical models were developed to describe the following phases of the activated sludge process.

1. BOD removal
2. Oxygen consumption
3. Sludge production

Prototype design formulations were also derived for gravity liquid-solids separation.

The reaction for BOD removal involves the consumption of organics by organisms for conversion to new cells and end products of CO_2 and water.

The process reaction was expressed in terms of first order kinetics and plug flow hydraulics:

$$\frac{L_e}{L_a} = (1-E) = e^{-k'S_A.T} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (12)$$

Where: k' = a biological rate constant in 1/ppm x hr

S_A = aerator mixed liquor solids in ppm

T = aeration detention time in hours

L_a = BOD applied to aerated tank in ppm

E = BOD removal efficiency

Data correlations using Equation 12 were made on semi-log paper, plotting the log of L_e/L_a versus S_AT. The scope of the line of best fit is equal to $k'/2.34$.

During batch oxidation, a sharp reduction in rate constant may be evidenced as the reaction process approaches completion. A significant reactor BOD concentration may also persist, even after prolonged periods of aeration. In either case, the course of the reaction can be subdivided into two phases and a rate constant established for each phase. In many instances the value of the rate constant for the second or retardant phase may be so small in comparison to that of the first phase as to be considered zero.

Recognizing the presence of a limiting effluent BOD concentration, the parameters of Equation 12 are modified to describe the removal of that fraction of the BOD above the limiting value. The modification takes the following form.

$$L'_a = L_a - L_m \qquad L'_e = L_e - L_m \qquad \ldots\ldots \quad (13)$$

Where: L_m = limiting BOD concentration, ppm

The biological reaction rate constant for organic removal above the limiting value is then expressed as:

$$\frac{L'_e}{L'_a} = e^{-k' S_A . T} \quad \ldots\ldots \quad (14)$$

The value of the limiting concentration, L_m, may be obtained by analyzing the velocity of BOD removal, $U_L = L_r/S_A \cdot T$ over small time intervals during the course of the batch reaction. The velocity of removal will approach zero as the BOD remaining approaches a limiting value. The BOD concentration at which the velocity equals zero is equal to L_m.

Temperature Effects

The effects of mixed liquor temperature changes on BOD removal rates are expressed in terms of the Arrhenius relationship using $\theta = 1.02$.

The value of $\theta = 1.02$ has found general acceptance for activated sludge performance.

During this study all batch removal runs were conducted at a constant temperature of 20°C (68°F). Biological rate constants are reported at a standard temperature of 20°C. Conversion of study values to prototype design temperatures may be made through the use of the Arrhenius relationship.

BOD Removal Performance

The BOD, suspended solids and oxygen uptake data obtained from a typical batch run are shown in Figure 12.

Reactor BOD concentrations persisted after extended period of aeration. Persistance of BOD concentrations may be attributed to a number of biological phenomena. The yeast effluents are high in organic nitrogen. Conversion of the organic nitrogen to ammonia and the high sludge age of the continuous sludge generators may have provided the conditions necessary for nitrification. BOD values at the end of the reaction would then include the demand for oxidation of nitrogen as well as carbon.

Endogenation of mixed liquor organisms is accompanied by a lysis of cellular material. Solubilization of lysed organics contributes to the presence of BOD after extended aeration periods. The ratio between mixed liquor solids and organics remaining in a batch reactor is considerably higher than that of a continuous reactor operating with sludge recirculation. The BOD of the organics derived from continuous sludge lysis in a batch reactor can then represent a significant and persistant concentration of apparently non-removable BOD.

FIGURE 12

TYPICAL BATCH ACTIVATED SLUDGE REACTION
YEAST EFFLUENT : SEWAGE = 1 : 5.5

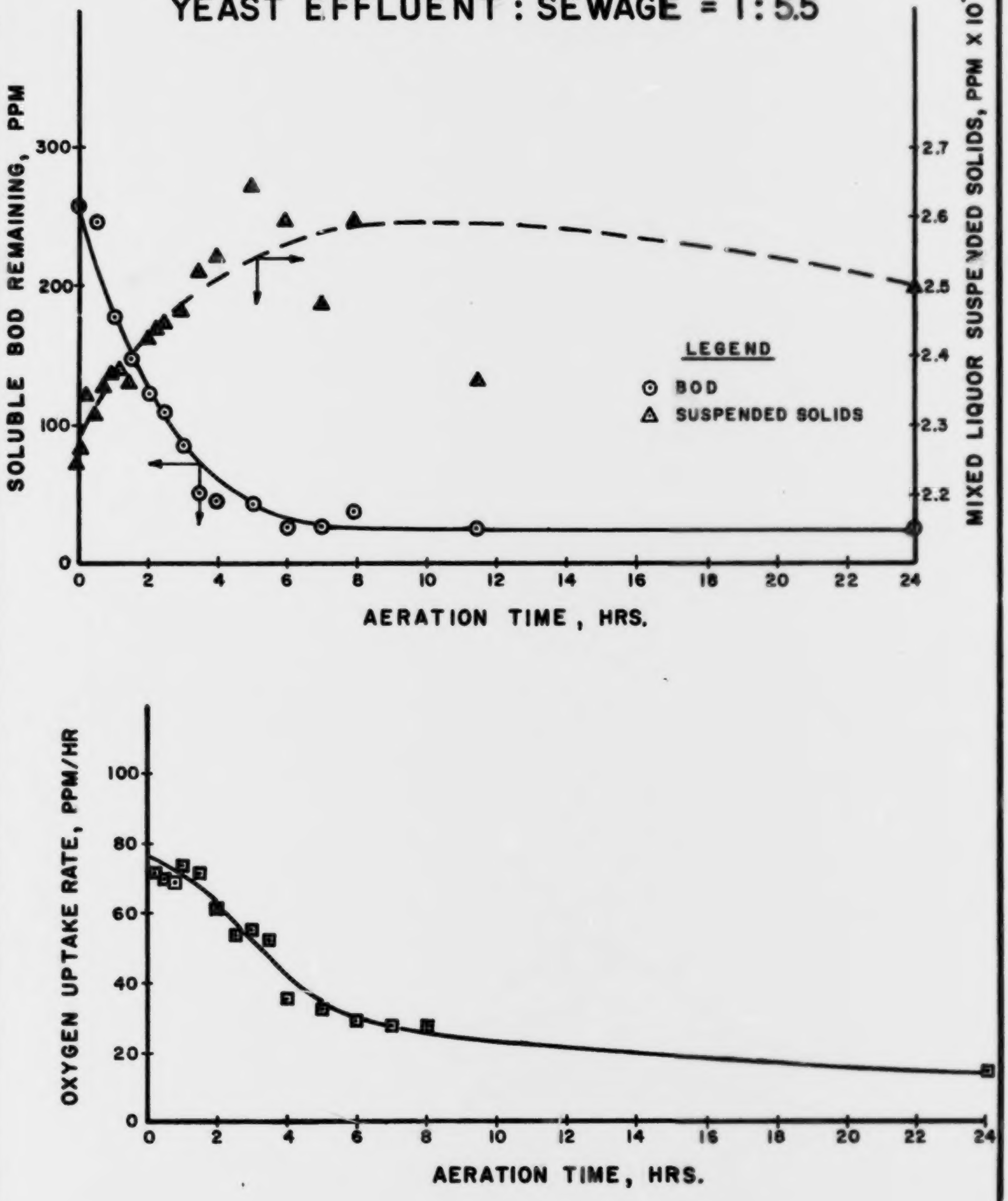


FIGURE 13

ACTIVATED SLUDGE BOD REMOVAL

SERIES #4-YEAST EFFLUENT : SEWAGE = 1:5.5

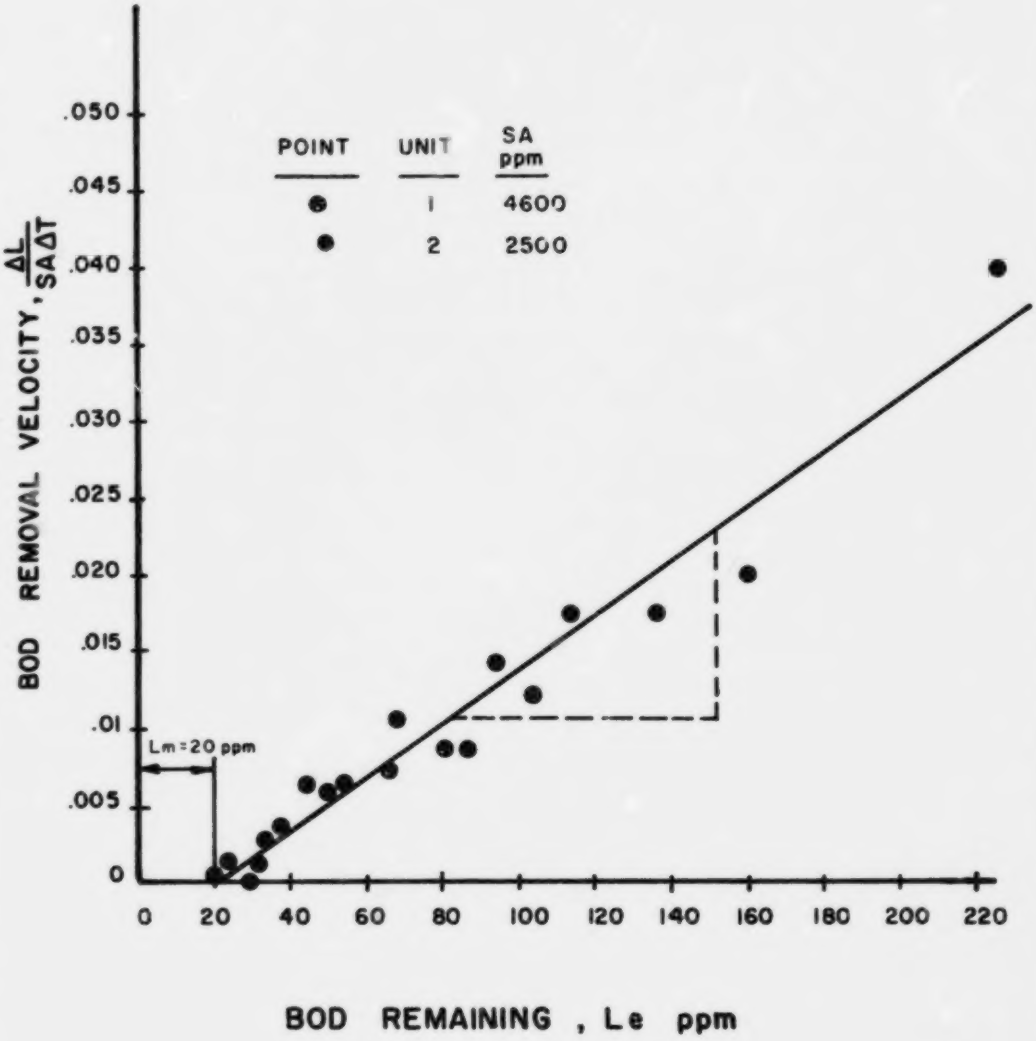


FIGURE 14

ACTIVATED SLUDGE BOD REMOVAL

SERIES # I YEAST EFFLUENT : SEWAGE = 1:3

PRETREATMENT BY TRICKLING FILTER

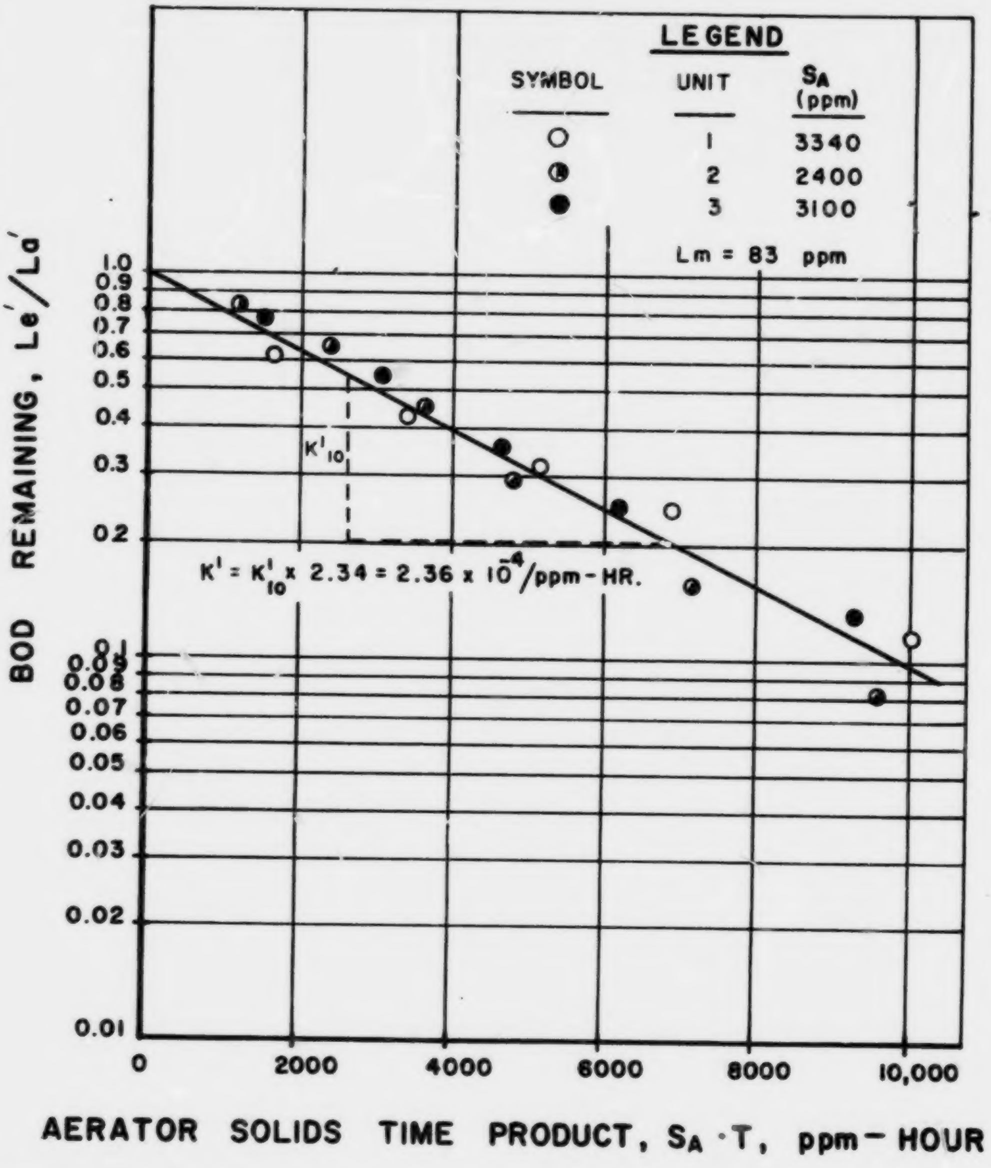


FIGURE 15

ACTIVATED SLUDGE BOD REMOVAL
SERIES # 2 YEAST EFFLUENT : SEWAGE = 1:3
PRETREATMENT OF YEAST EFFLUENT BY ANAEROBIC DIGESTION

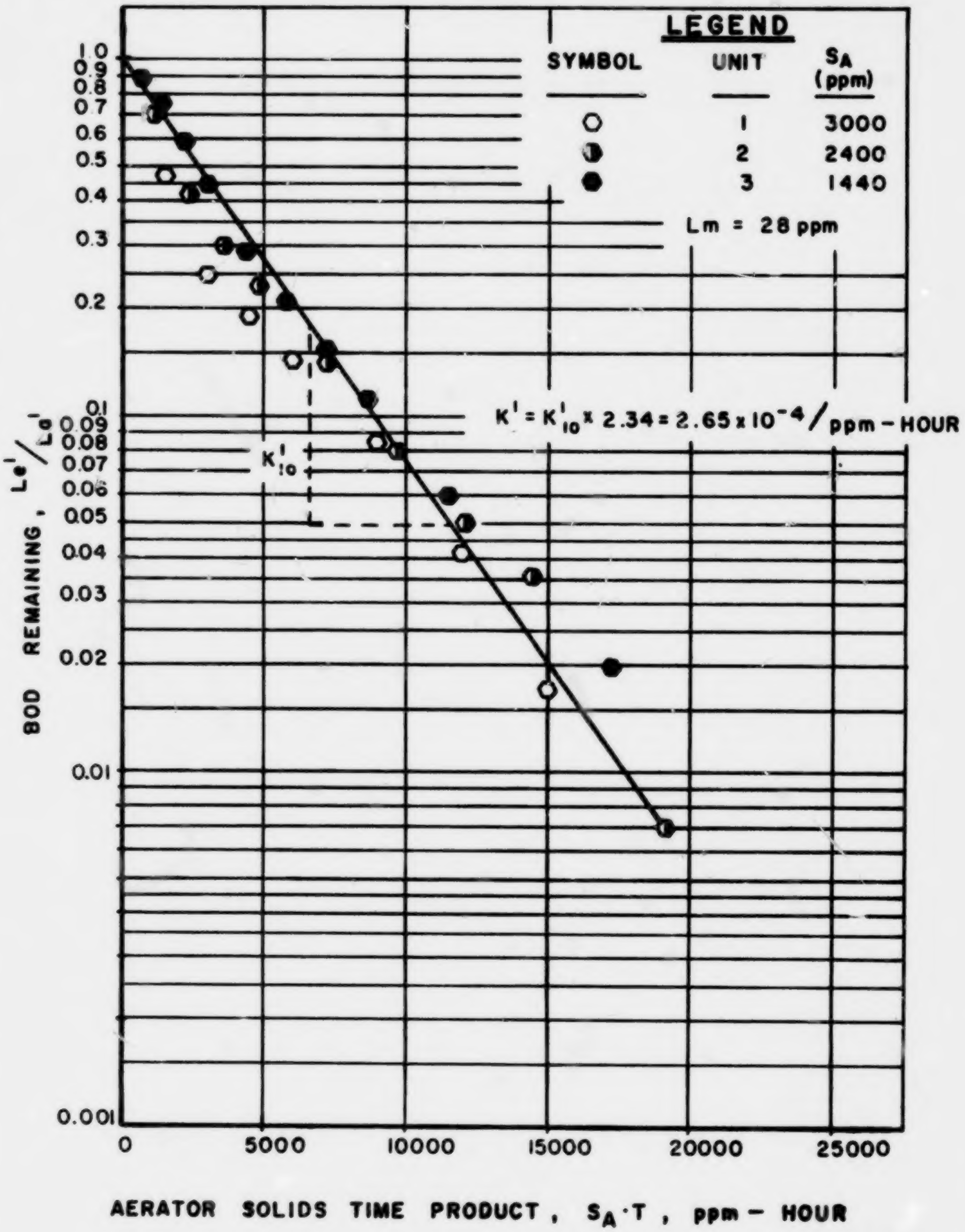


FIGURE 16

ACTIVATED SLUDGE BOD REMOVAL

SERIES #3 YEAST EFFLUENT : SEWAGE = 1:3

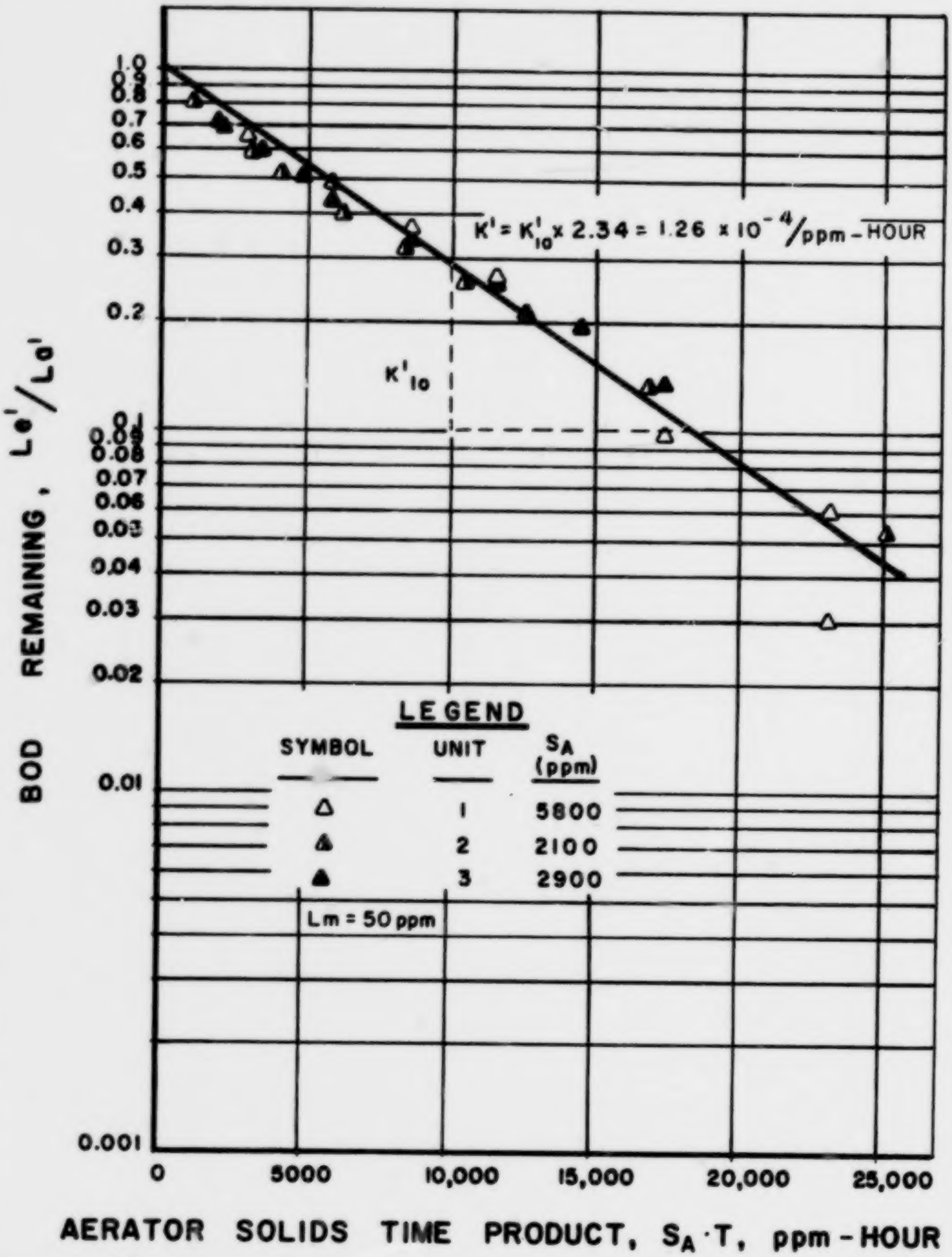
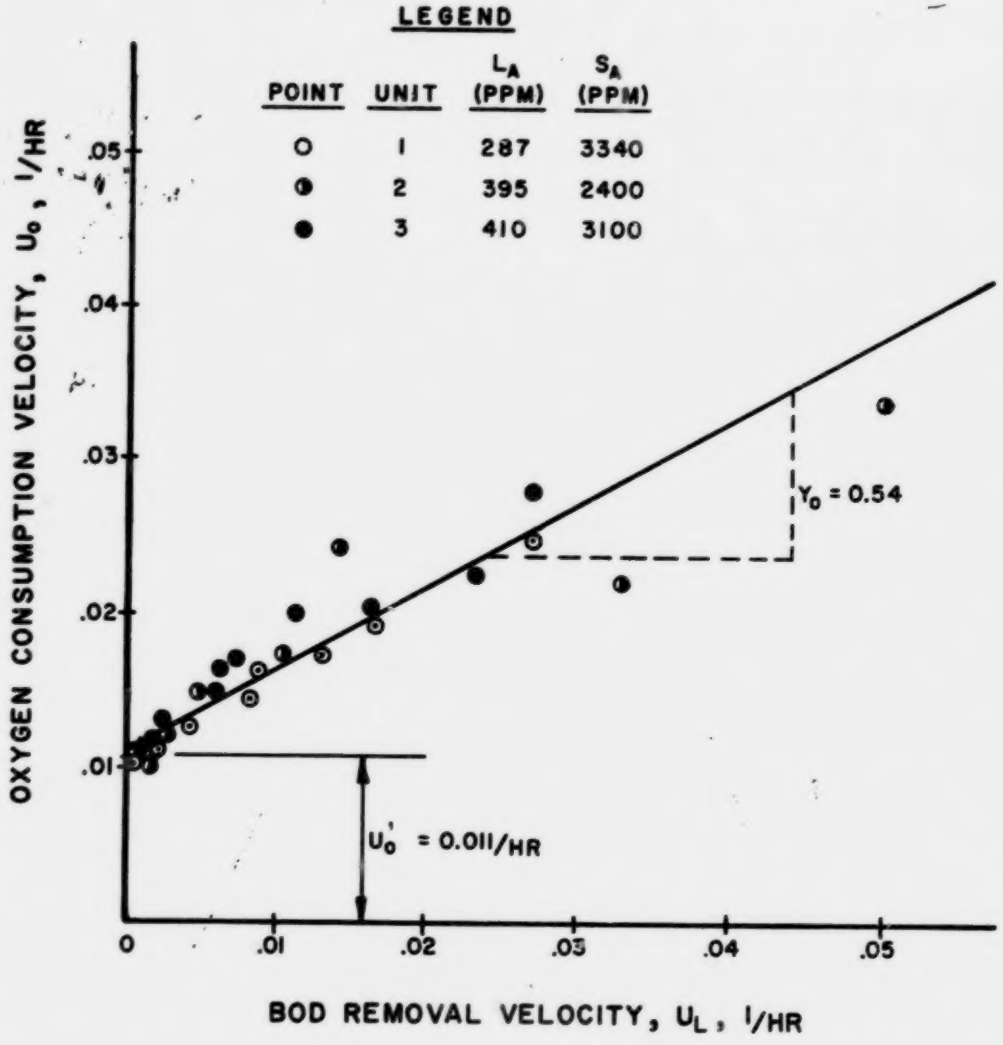


FIGURE 17

ACTIVATED SLUDGE OXYGEN REQUIREMENTS SERIES # I - YEAST EFFLUENT: SEWAGE = I:3 PRETREATMENT BY TRICKLING FILTER



An illustration of the determination of the value of the limiting BOD concentration for a typical batch series is presented on Figure 13. The velocity of BOD removal, $\Delta L/Sa\Delta t$, was determined at 30 minute intervals and related to the average BOD present during the interval. The first order kinetics of the reaction is illustrated by the linearity between removal velocity and BOD concentration. The existence of a limiting BOD concentration (L_m) at which removal velocity reaches zero is also evidenced. Graphical analyses of the type shown on Figure 13 were used to determine the value of (L_m) for each series of investigations.

Graphical analyses of the laboratory results, in accordance with Equation 14, for the flow sheets studied are shown on Figures 14 to 16.

Table 8 summarizes the biological reaction rates and limiting BOD concentrations observed during each series. The rate constants shown are compared with a $k' = 1.1 \times 10^{-4}$/ppm x hours for average municipal sewage. Biological pretreatment of the yeast effluent resulted in an increase in the reaction rate.

Oxygen Consumption

Oxygen requirements are divided between growth of new cells and endogenation of existing cells.

The total oxygen consumption is related to BOD removal and sludge endogenation as follows:

$$U_O = Y_O \cdot U_L + U_O' \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (15)$$

Where: U_O = Oxygen consumption velocity, lbs. of oxygen used per hour per lb. of mixed liquor sludge.

Y_O = Oxygen required for growth, #O_2 per lbs. of BOD removed.

U_L = BOD removal velocity, lbs. of BOD removed per hour per ob. of mixed liquor sludge

U_O' = Endogenous oxygen velocity, lb. oxygen required per hour per lb. of mixed liquor sludge.

Activate sludge oxygen requirements for batch studies are illustrated using data from Series 1 as shown on Figure 17.

Values of Y_O and U_O' are summarized in Table 9. Values obtained from an analysis of operating data of 45 municipal activated sludge plants ranging in size from 1 to 800 mgd by Hazeltine, have been included for comparison.

Table 8 Summary of Biological Reaction Rate

Series	Method of Pretreatment	Biological Reaction Rate (x 10^{-4}/ppm-hour)
1	Trickling Filtration of Combined Effluent	2.36
2	Anaerobic Digestion of the Yeast Effluent	2.65
3	None	1.26
4	None	1.93

Table 9 Yeast Effluents: Oxygen Consumption Parameters Batch Activated Sludge Study

Series #	Y_o ($\#O_2/\#$BOD removal)	U'_o ($\#O_2/\#S_A$-Hours)
1	0.54	0.011
2	1.0	0.020
3	0.32	0.013
4	0.67	0.010
Domestic Sewage Average	0.50	0.004

Analyses of the economics of activated sludge application will require consideration of the power consumption for aeration. Oxygen consumption and power consumption for BOD removal will vary with the efficiency of BOD removal and with the effluent combination being treated. Oxygen consumption per pound of BOD removed may be used to evalute power needs and is related to process design parameters as follows:

$$\frac{\#O_2}{\#L_r} = Y_o + \frac{U'_o}{E \cdot f} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (16)$$

O_2/L_r will reach a maximum at maximum BOD removal efficiencies. Power requirements for mixing will depend upon tank geometry and equipment type.

Selection of aeration equipment will require consideration of the oxygen uptake rates to be supplied. As BOD concentration to the aeration tanks increase, uptake rates will increase to the point where mechanical aeration or pure oxygen equipment will become desirable. The average aeration tank uptake rate is expressed in terms of oxygen consumption velocity as follows:

$$\overline{UR} = (U_o)\ (S_a) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (17)$$

Where:

$\overline{UR}$ = Average tank uptake rate in ppm/hr.

U_o = Oxygen consumption velocity in 1/hr.

S_a = Aeration mixed liquor solids concentration in ppm

The distribution of uptake rate throughout the aerated tank may be determined after tank mixing characteristics have been selected.

Sludge Production

Net biological sludge production in an activated sludge unit is expressed as the net of the growth and endogenation processes. Sludge yield due to BOD growth is reduced by endogenation of the sludge mass under aeration. A relationship similar to that derived for digestion may be written to describe the net yield as follows:

$$\frac{\Delta s}{L_r} = Y_s - \frac{U'_s}{U_L} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (18)$$

Where: $\frac{\Delta S}{L_r}$ = Net sludge produced per pound of BOD removal.

Y_s = Sludge yield in lbs. of suspended solids/lb. of BOD removed.

U_L = Velocity of BOD removal, (1/day)

U_S' = Endogenous sludge velocity, (percent/day), lbs. of suspended solids destroyed per lb. of mixed liquor suspended solids per day.

The net solids yield during a batch removal study will only be in the order of 100-200 ppm under the high BOD concentrations used in this study. Mixed liquor concentrations in the order of 3000 ppm were maintained in the batch reactors. The yield will be 3 percent to 7 percent of the total sludge mass under aeration. Laboratory suspended solids measurements, via the Gooch crucible technique, are not generally within this degree of accuracy. A 5.5 cm buchner funnel fitted with glass fiber pads was substituted for the Gooch in an effort to obtain higher accuracy. The suspended solids versus time data, for a typical batch run shown in Figure 12 are an average of triplicate buchner funnel determinations. Even with this amount of care, the suspended solids measurements exhibit high scatter. Sludge yield values estimated from measurements of the type shown on Figure 12 range from .8 to 1.5 for Y_s and from 0.06 to 0.20 for U_S'.

Sludge yields may be approximated from the oxygen demand parameters. Yield values using this estimation vary from .5 to .8 #/#.

Estimates of sludge production from activated sludge may be made using these ranges as guides.

Solids - Liquid Separation

The use of high mixed liquor solids concentrations require that the solids liquid separator following the aerator be designed for both effluent clarification and sludge compaction.

The separator most often employed is a gravity clarifier. The unit is designed to provide a clarified effluent as well as a thickened underflow for return to the aerator and for subsequent sludge disposal facilities.

Choosing an aerator solids concentration of 3000 ppm and a thickener underflow concentration of 15,000 ppm, a compaction ratio of 5.0 is obtained.

A mass loading of 20 lbs/SF day is calculated. In terms of clarifier design parameters an overflow rate of 480 gal/SF day is indicated.

THE BETTER WHEY - A DILEMMA

by

Sidney Boxer*

Because of the current wave of environmental concern, the problem of food-processing wastes has been moved to the front pages of newspapers from the back benches of the laboratories. The dual pressure from the public and the various governments has accelerated the need for devising methods of abating the pollution by food wastes. Simultaneously, the competitive demands of the market dictate minimal cost procedures or, even better, the recovery of these wastes.

The dilemma faced by all food processors is the same - who goes first? Unless all the processors in a particular food category are required at the same time to abate their pollution, then, obviously, there will be a cost disadvantage to those who comply. The answer might be, as suggested by some Washington officials, a monetary assessment against the non-compliers. I would go further and suggest that, if there is an assessment, the funds be placed in an industry pool for research and development to resolve the pollution problems of the particular industry.

The cheese industry has the problem of whey waste, a heavy pollutant because of its high BOD, and yet a food by-product with excellent nutritive value. However, it costs at least $2,000,000., just for the plant and equipment to recover the whey.

This poses another problem - the economics of the disposition of whey clearly indicates that large scale processing is necessary. Of approximately 700 cheese plants in the country, only 10% produce sufficient volume to justify their own whey drying plant.

DAIRY RESEARCH & DEVELOPMENT CORP., in its brochure to the cheese industry, has suggested the establishment of regional drying plants to service the smaller producers within a limited geographic area. We are presently organizing nationwide marketing and distribution facilities which will provide the smaller producers, as well as the larger ones, with the opportunity of equal participation.

A brief background of the history of our project may be enlightening, or at least evoke some sympathy. It all started with "Little Miss Muffet" and her damnable curds and whey. That nursery rhyme has turned into 23 billion lbs. of liquid whey per year, equivalent on a BOD basis to pollution by 10,000,000 people. To build sewage plants to accommodate this waste would cost about $800,000,000., with an annual operating expenditure of about $30,000,000.

---

*President, Dairy Research & Development Corp., New York, N. Y.

Fortunately for us, Washington is impressed by large numbers and, I must admit, the positive value of converting such a large quantity of waste into edible food. In December, 1968, DRD was awarded a grant by the then FWPCA of the Dept. of the Interior, now the WQO of the Environmental Protection Agency, for its research and demonstration project for elimination of pollution by whey, and utilization of the whey as a food or in food products.

In developing the project, we had excellent cooperation from DAIRYLEA of New York. It supplied the plant facilities at Vernon, New York, as well as a great deal of engineering and similar assistance. DAIRYLEA is to be commended for its foresight and willingness to cooperate in this project, which will be of ultimate benefit to the entire cheese industry.

After much soul-searching, we had decided that the only solution to the disposal of whey was by the recovery of the whole whey as a food. Following three years of investigation into many systems, the most efficient and economical method appeared to us to be spray drying. The technical problem was to attain a large scale drying process that was economical and yet productive of a fine, non-hygroscopic powder fit for human consumption. We had a further problem, in that we were particularly to undertake the drying of cottage cheese whey, of higher titratable acidity than the whey from hard cheeses.

From the standpoint of time, we were fortunate that THE DeLAVAL SEPARATOR COMPANY had been conducting experiments and had built a good size pilot unit at its River Falls, Wisconsin, plant. Following numerous tests over a period of two years at the pilot plant, we then commissioned DeLAVAL to build a commercial plant for our demonstration project. They also had to incorporate a special system for the purpose of producing a non-hygroscopic powder from cottage cheese whey.

This unit was installed last July at our facilities in Vernon, New York, and a number of shake down tests have taken place. We have discovered a number of problems of interest to the chemical and technical men amongst you.

The higher acidity of cottage cheese whey, a pH of about 4.5, can inhibit the proper crystallization necessary to obtain the non-hygroscopicity of the finished product. Even more, the per cent of solids from the evaporator to the crystallizer is critical, as well as the temperature, time and cooling rate factors necessary to obtain the desired alpha crystals and control mutarotation. Without a doubt, the evaporator must have sufficient capacity to bring the liquid whey to a proper percentage of solids before crystallization and drying. We do believe all the problems have been overcome and around April 1st, we expect to go into substantial production runs to demonstrate the feasibility of large scale drying of cottage cheese whey to a non-hygroscopic powder. In the concept of recycling, whey offers the greatest challenge to remove it as a pollutant, and the unlimited opportunity of utilization of a product of high nutritive value. DRD is proceeding with research and development of whey powder as additives, in beverages, baked goods, etc.

Not being an engineer, I will have to leave the more thorough discussion of the chemical problems of cottage cheese whey, and the technical problems of drying the whey, to others more qualified at this conference.

I would like to say that the administrative and technical staffs of both EPA and the Department of Agriculture have been most generous in their assistance. There is no doubt in my mind that the partnership of government and industry is necessary to solve the vast pollution problems of this country and, indeed, the world. With government supplying the "seed," and industry doing the hoeing and plowing, the nation will reap the ecological benefits.

MEMBRANE PROCESSING OF COTTAGE CHEESE WHEY FOR POLLUTION ABATEMENT

by

Dr. Robert L. Goldsmith*, Dr. David J. Goldstein*,
Bernard S. Horton*, Sohrab Hossain*, and Dr. Robert R. Zall**

ABSTRACT

A two-step membrane process has been demonstrated for the treatment of cottage cheese whey. The process produces valuable protein and lactose by-products while reducing the BOD of the whey effluent. The process has been studied in detail in prototype experiments at Abcor, Inc., Cambridge, Mass., and in a 10,000 lbs/day pilot plant at Crowley's Milk Company, Binghamton, New York.

In the two-step process, a protein concentrate is first recovered in an ultrafiltration operation. In the second step, ultrafiltration permeate (de-proteinized whey) is concentrated by reverse osmosis to provide a lactose concentrate. The protein concentrate can be further concentrated and/or dried; and the lactose concentrate can be further concentrated and lactose recovered by crystallization, or otherwise processed. Alternatively, the membrane concentrates can be used directly as fluid products.

Operation of the pilot plant was successful and almost troublefree. BOD reduction of the raw whey was about 97 percent, from an initial value of about 35,000 mg/ℓ to less than 1,000 mg/ℓ. Membrane life was excellent, and membrane fluxes were economically high. Membrane flux, membrane rejection, and membrane life for both ultrafiltration and reverse osmosis sections of the pilot plant are discussed in this paper.

The pilot plant produced protein and lactose products with low total plate counts, and nil coliform counts. Using the cleaning procedure developed in the prototype program, total plate counts were typically below 50,000 org/ml, or less than the limit for Grade A milk. Thus, the pilot plant was of a sanitary design and produced dairy grade products.

Projected capital cost for a 250,000 lbs cottage cheese whey/day demonstration plant is $610,000. This includes both the ultrafiltration and reverse osmosis sections of the plant, tanks, and a building to house the plant. Projected operating costs are $196,000 per year. Projected income from utilization of the protein and lactose concentrates makes the process profitable and results in an attractive return on investment.

---

*Abcor, Inc., Cambridge, Mass.
**Crowley's Milk Co., Binghamton, N. Y.

Preceding page blank

During 1971 the full-scale plant will be designed, built and put into operation.

This project is partially financed by the Water Quality Office of the Environmental Protection Agency under Grant No. 12060 DXF, to Crowley's Milk Company.

INTRODUCTION

Background

The manufacture of cheese from either whole or skim milk produces, in addition to the cheese itself, a greenish-yellow fluid known as whey. Whole milk is used to produce natural and processed cheeses such as cheddar, and the resulting fluid by-product is called sweet whey, with a pH in the range of 5 to 7. Skim milk is the starting material for cottage cheese and gives a fluid by-product called acid whey, with a pH in the range of 4 to 5. The lower pH is a result of the acid developed during or employed for coagulation.

Each pound of cheese produced results in five to ten pounds of raw fluid whey. The high organic content of whey leads to a severe disposal problem. However, these organic materials have a high nutrient content and, if properly recovered, could provide useful products. Table 1 shows typical compositions of whey and dried whey solids. Over 70 percent of the nutrients from skim milk show up in acid whey, including soluble protein and lactose.

The organic nutrients of whey, which go unused, place a costly burden on sewage systems and waterways. The biological oxygen demand (BOD) of whey has been noted as ranging from 32,000 to 60,000 ppm(1,2). Most of this BOD is due to the lactose. Specific BOD values for cottage cheese wheys are between 30,000 and 45,000 mg/ℓ, depending primarily on the specific cheese-making process used. Every 1,000 gallons per day of raw whey discharged into a sewage treatment plant can impose a load equal to that from 1,800 people. This is partially passed into streams in most cases because BOD removal is not complete. Every 1,000 gallons of raw whey discharged into a stream requires for its oxidation, the dissolved oxygen in over 4,500,000 gallons of unpolluted water(3).

Table 1. Average composition of whey products.

Product	Water	Nitrogenous Matter	Fat	Lactose	Acid	Ash
Raw Cheese Whey	93-94%	0.7-0.9%	0.05-0.6%	4.5-5.0%	0.2-0.6%	0.5-0.6%
Dried Whey	2-6	12-14	0.3-5.0	65-70	2-8	8-12

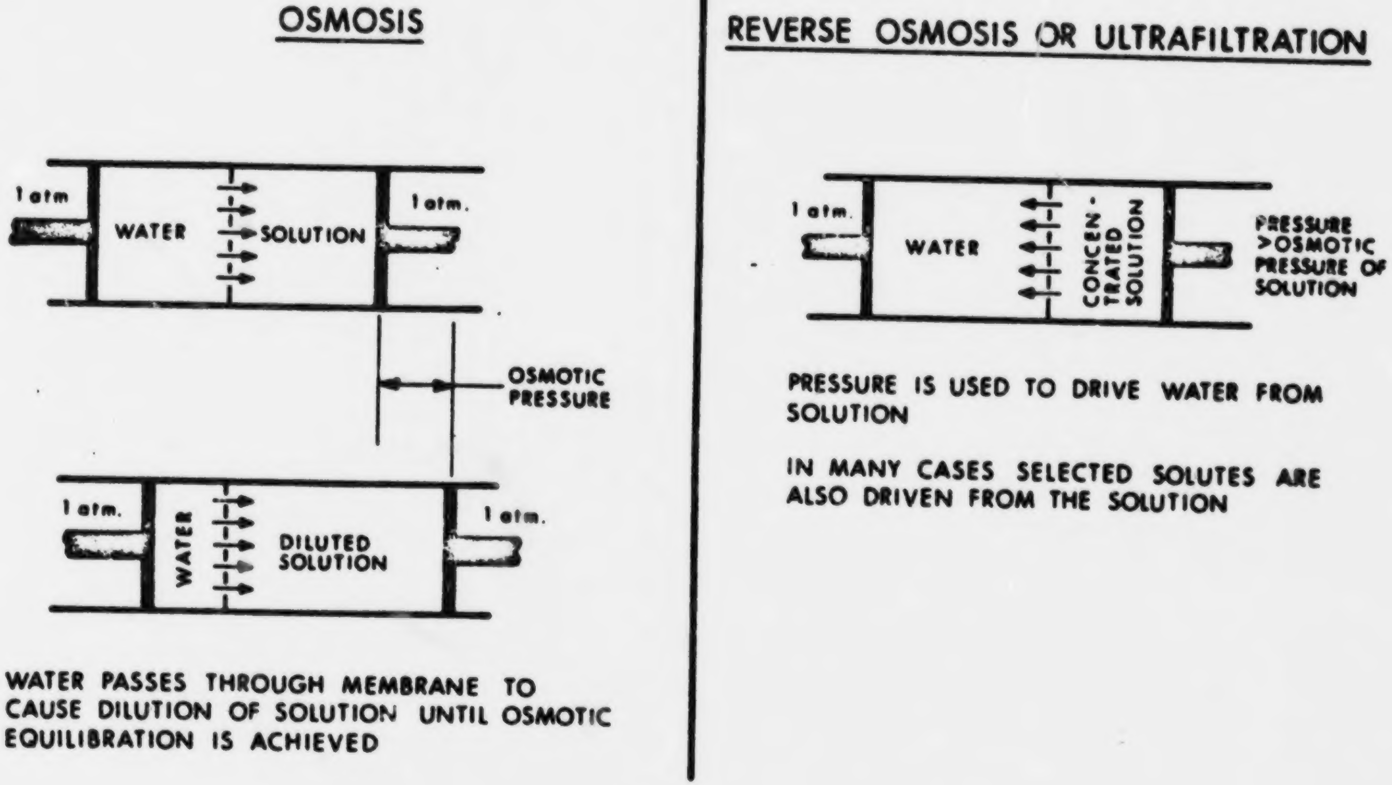
Recent statistics give BOD's of about 0.2 pounds per pound of cottage cheese curd. Combining this with production statistics, a total BOD removal of over 200 million pounds would have been required in 1970 for complete waste treatment. Considering that at the very best only half of the cottage cheese whey produced is currently put to good purpose and that curd was water can contain up to 3 percent solids, the disposal problem is severe.

The waste treatment technique described in this paper utilizes membrane separation processes to remove organic material from acid (cottage cheese) whey, thereby reducing its BOD to levels which can be easily handled. This BOD reduction is accomplished in such a way that protein and lactose or, as an alternative, concentrated whole whey, are produced; and an economic credit rather than a cost for the overall process operation is realized. Although the demonstration has been for acid whey treatment, the technology is applicable to sweet wheys.

Proposed Membrane Process

A two-step membrane separation process has been developed for the treatment of cottage cheese whey. In this process, whey is simultaneously fractionated and concentrated to give protein and lactose byproducts. The final effluent has a low biological oxygen demand (BOD) and is expected to be suitable for reuse within the cottage cheese plant. One application, for example, is in curd washing. If the effluent is discharged, a final treatment for residual BOD removal may be required, depending on local and state regulations.

The two-step whey treatment process is based on the application of ultrafiltration (UF) and reverse osmosis (RO). Reverse osmosis has been extensively studied during the past ten years under funding from the Office of Saline Water, the bulk of this work focusing on desalination of brackish and sea waters. Additional publicity has been given to its application to whey concentration by the United States Department of Agriculture(3,4,5). Ultrafiltration is a variation of this membrane separation technique. Figure 1 shows the basic concept involved. A semi-permeable membrane separates water and a solution. In the absence of a hydrostatic pressure differential, water will permeate the membrane so as to dilute the solution. A counter pressure can be applied to the solution side to reverse water transport. The amount of pressure required to achieve a static equilibrium is termed the osmotic pressure. Reverse osmosis is simply the application of a pressure greater than the osmotic pressure, which drives water from the solution side of the membrane to the water side, and permits concentration of the solution. The membrane plays the most critical role in the process. By varying the properties of the membrane, one can control the retention or passage of selected solutes. When the solute molecules are large, for example whey proteins, the osmotic pressure is quite low and a membrane with relatively large pores can be used at low operating pressures, e.g., 10 to 100 psi. This is termed ultrafiltration. Referring to Figure 2, the membrane may be called "loose," that is, lower molecular



OSMOSIS

WATER PASSES THROUGH MEMBRANE TO CAUSE DILUTION OF SOLUTION UNTIL OSMOTIC EQUILIBRATION IS ACHIEVED

REVERSE OSMOSIS OR ULTRAFILTRATION

PRESSURE IS USED TO DRIVE WATER FROM SOLUTION

IN MANY CASES SELECTED SOLUTES ARE ALSO DRIVEN FROM THE SOLUTION

FIGURE 1

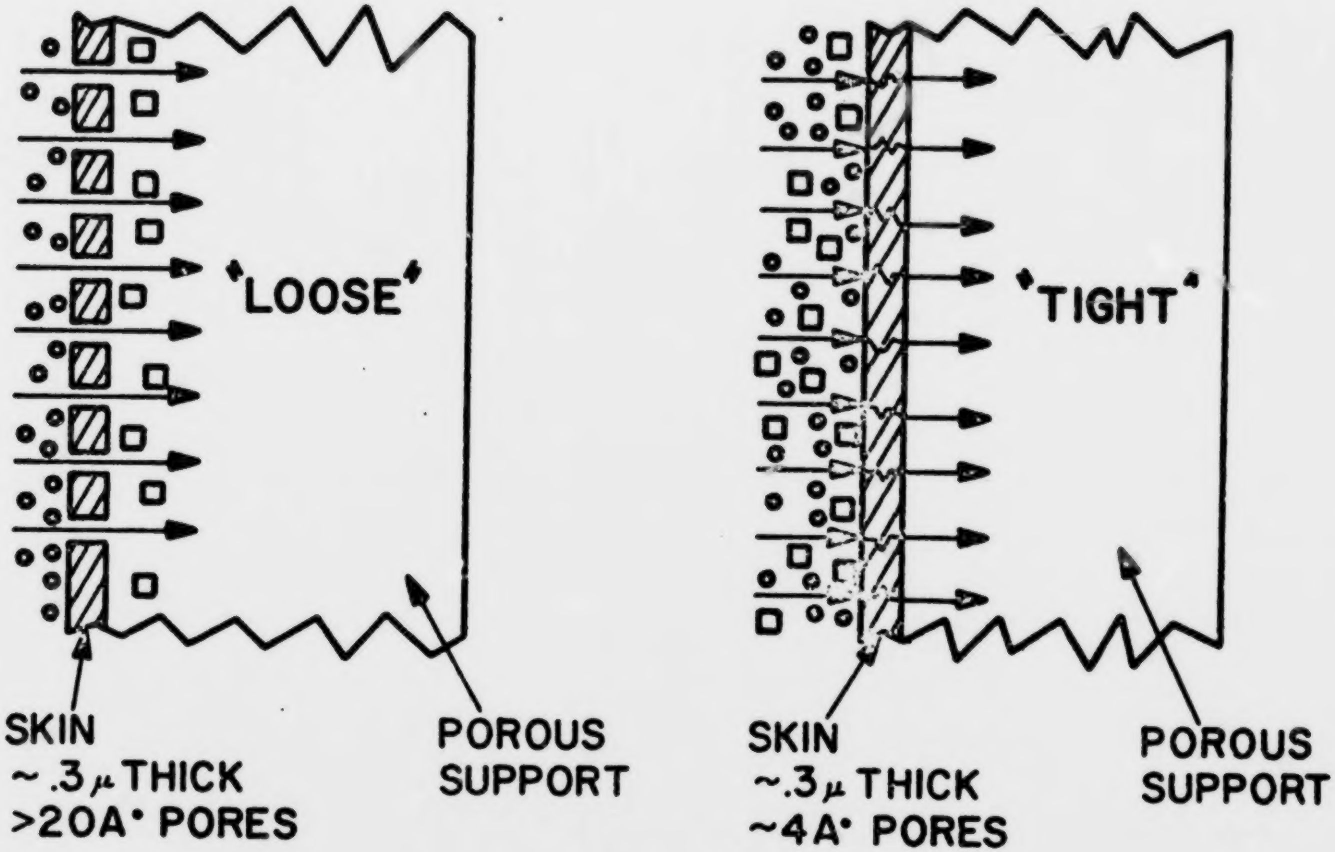


FIGURE 2-FLOW THROUGH MEMBRANES

weight solutes will pass through the membrane and will not be retained in the concentrate. In reverse osmosis, solutions of small molecules with moderate to high osmotic pressures are retained, and the required driving force is considerably higher, ranging from several hundred psi to over one thousand psi. Higher operating pressures are required because of the substantial osmotic pressure of salt and sugar solutions, and also because of the greater resistance to water transport of RO membranes. Again referring to Figure 2, a "tight" membrane is to be employed.

Figure 3 shows a simplified flow sheet for the two-step whey treatment process. Cottage cheese whey, with or without filtration for fines removal, is introduced into a low pressure UF unit (step 1). In this operation, whey is concentrated 10- to 30-fold by volume. Ultrafiltration membranes are used which retain only the whey proteins. Thus, it is possible to obtain a protein concentrate with a higher proportion of proteins in the dissolved solids, since lactose, non-protein nitrogen, lactic acid, and minerals pass through the membrane. Operation is typically in the pressure range of 10 to 100 psi, and at temperatures of 60 to 130°F. The protein content of raw whey can be increased from an initial value of about 0.6 percent up to levels approaching 20 percent in this step. Composition of the protein concentrates on a dry solids basis is shown as a function of the degree of water removal in Figure 4. It is apparent that at water removal levels exceeding 95 percent, protein concentrate streams can be generated with a protein composition up to 80 percent. Concentrates of this composition were in fact generated in the course of the experimental program.

The permeate (ultrafiltrate) from the UF unit is introduced into a second membrane step. In an RO operation, this stream is concentrated from approximately 6 percent solids to 20-25 percent solids. Typical operation would be in the pressure range, 500 to 1500 psi, and at a temperature of 60 to 100°F. The membrane in the RO section is chosen so as to retain as great a proportion of the organic solutes as possible, resulting in the permeate having a low BOD.

The final effluent from the RO section can either be reused within the dairy or cheese plant or discharged, with or without treatment for residual BOD removal. Where pollution control regulations are not overly stringent, a moderate salt rejection membrane can be used in the RO section to permit partial desalting and lactic acid removal from the lactose concentrate. In general, from the point of view of pollution control, this option will probably not be exercised.

The protein concentrate can either be used directly by incorporation into food products, or it can be dried. Drying may be preceded by concentration by vacuum evaporation. The lactose concentrate can be further concentrated by evaporation and the lactose can be recovered in a simple crystallization operation.

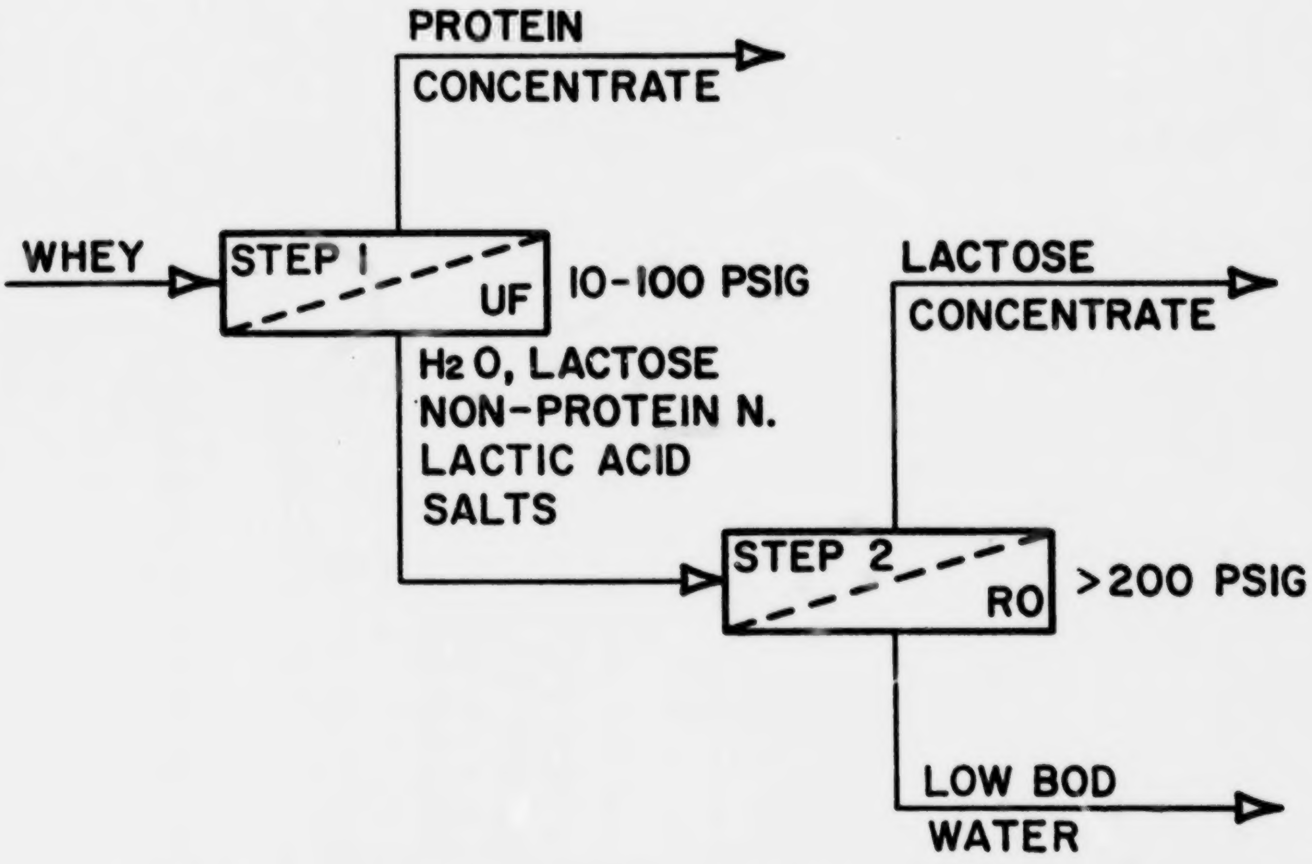
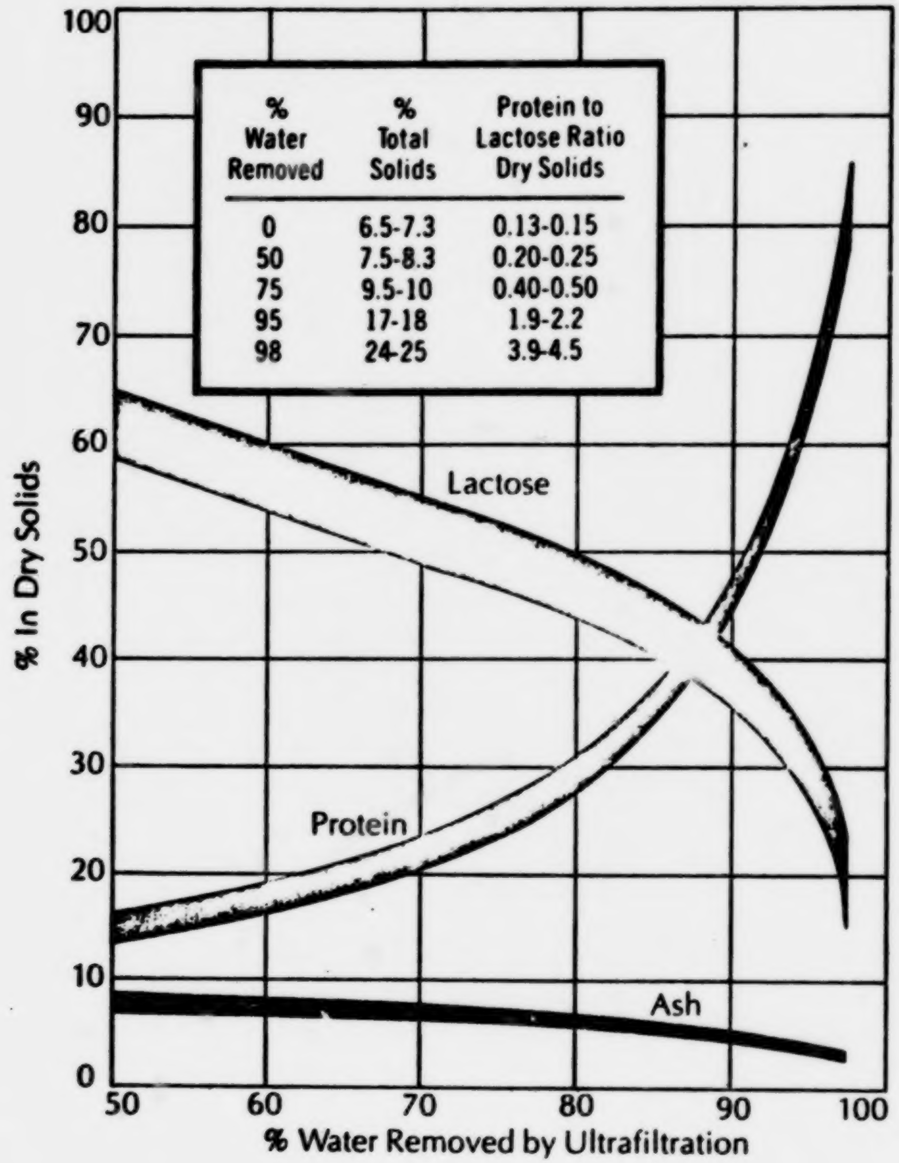


FIGURE 3 -MEMBRANE PROCESS FOR WHEY TREATMENT--FLOW SCHEMATIC



% Water Removed	% Total Solids	Protein to Lactose Ratio Dry Solids
0	6.5-7.3	0.13-0.15
50	7.5-8.3	0.20-0.25
75	9.5-10	0.40-0.50
95	17-18	1.9-2.2
98	24-25	3.9-4.5

FIGURE 4: COMPOSITION OF WHEY PROTEIN CONCENTRATE

Another process alternative, which has been only briefly explored in this program, is the direct concentration of whole whey by RO. This approach has been examined by others(3,4,5), and appears to be attractive for cheese producers with small volumes of whey. Concentration on-site would precede transportation to, and processing at, a central facility. However, a satisfactory cleaning program needs to be defined prior to wide use.

Following extensive prototype experiments during a six-month period at Abcor, Inc., a two-stage pilot plant was built. The unit, designed and built by Abcor, was shipped to Binghamton, New York for a four-month period of operation. The unit has since been shipped to and out in daily operation at Crowley's LeFargeville facility.

This paper reports on the pilot plant operation. Results of prototype experiments are discussed in detail in the Phase I Report (now in process of review by WQO), and have been reported in part elsewhere(6,7,8,9). The prototype experiments focused on the examination of a wide variety of membrane systems and the effects of all major operating variables (temperature, pressure, time, concentration level, etc.). The pilot data are somewhat more restricted in scope, but cover the operation of a moderate scale facility on-site in a dairy--a good test of the performance and reliability of the equipment.

DESCRIPTION OF PILOT PLANT

A detailed description of the pilot plant and its operation is contained in the Phase I Report (presently under WQO review prior to publication). The following paragraphs present the major features of the pilot plant.

Ultrafiltration Section (Low Pressure)

The UF section of the pilot plant contains 210 ft^2 membrane area (192 Abcor HFA-180 tubular membranes). These are arranged in four parallel passes (modules) contained in a stainless steel cabinet, fitted with sprays for cleaning and sanitizing purposes. At a typical average flux of 13.5 gfd for high conversion, approximately 1,000 lbs of cottage cheese whey can be processed per hour.

Operation was batchwise; that is, one batch (or more) of whey was charged to the system per day and concentrated without adding additional whey. During operation, the feed was volumetrically concentrated 20-fold or higher, depending on the level of protein desired in the fluid concentrate. At the end of the run protein concentrate was recovered from the membrane unit by displacement with water or by draining.

The UF section is shown in Figures 5 and 6, installed on-site in Binghamton, N.Y. In Figure 5 the stainless steel sanitary cabinet is shown. A closeup of the tubular membranes inside the cabinet is given in Figure 6.

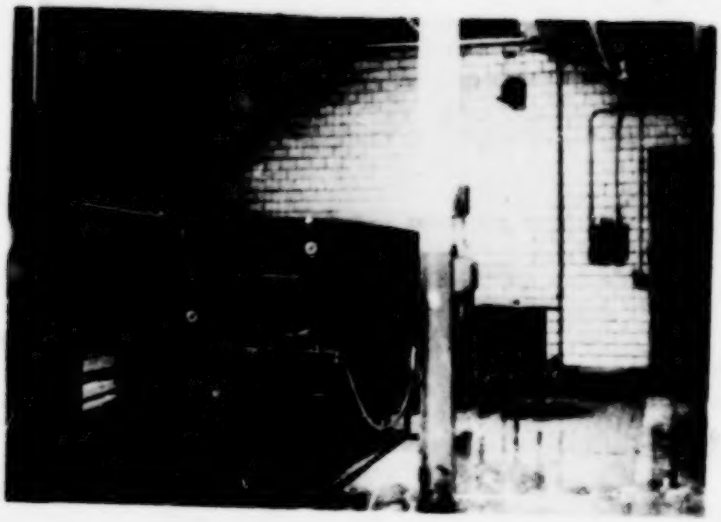


Figure 5
Pilot Plant
Sanitary Cabinet Housing Ultrafiltration Membranes

Figure 6
Pilot Plant
Ultrafiltration Membranes in Sanitary Cabinet

A separate clean-in-place system was used to mix and circulate cleaning and sanitizing solutions through the membrane unit (membranes, pumps, piping, etc.) and also through the cabinet spray pipes.

Reverse Osmosis Section (High Pressure)

The RO section of the pilot plant contains 210 ft^2 membrane area in the form of 42 American Standard TM 5-8 modules. All contain AS-197 membranes. The modules are mounted in an open rack (Figure 7) for convenient cleaning of the exterior surfaces. This equipment is presently manufactured by Abcor, Inc.

The high pressure RO section was used either to concentrate the lactose permeate from the UF section or whole whey - in either case producing a lactose concentrate and a low BOD effluent.

The system was designed such that the feed could be processed batchwise or continuously. For the latter, feed was taken from an interstage tank and pumped through the system, continuously removing both a fluid concentrate and a low BOD permeate.

Figure 8 shows the control panels and pumps for the three pumping stations.

The interstage tank is shown in Figure 5, just to the right of the UF membrane cabinet. In addition to accumulating permeate from the UF section to be used as feed for the high pressure section, the interstage tank was also used to mix cleaning and/or sanitizing solutions for the high pressure system.

OPERATION OF PILOT PLANT

General Performance

During the period from July 22 through December 1, 1970, the pilot plant was operated on a fairly regular basis. Operation was generally three days per week, with a fresh shipment of whey arriving each Monday. During this period, pilot plant performance was excellent. Capacity remained unchanged with time, with the UF section having a capacity of 20,000 lbs whey/20-hour day, and the RO section having a capacity of 10,000 lbs whey/20-hour day. The BOD reduction observed in the bulk of the program was from approximately 35,000 mg/ℓ to about 1,000 mg/ℓ (fresh, low-acid whey). Some exceptions were observed, in particular during periods when one (or more) of the RO high pressure modules developed a leak. In fact, the sole aspect of the pilot plant operation which was not entirely satisfactory related to the durability of the RO modules. At the beginning of the pilot plant operation, several developed leaks and had to be replaced. In addition, over the program period, four modules experienced tube ruptures. For the last two and a half months of operation, however, performance of the RO section was entirely satisfactory.

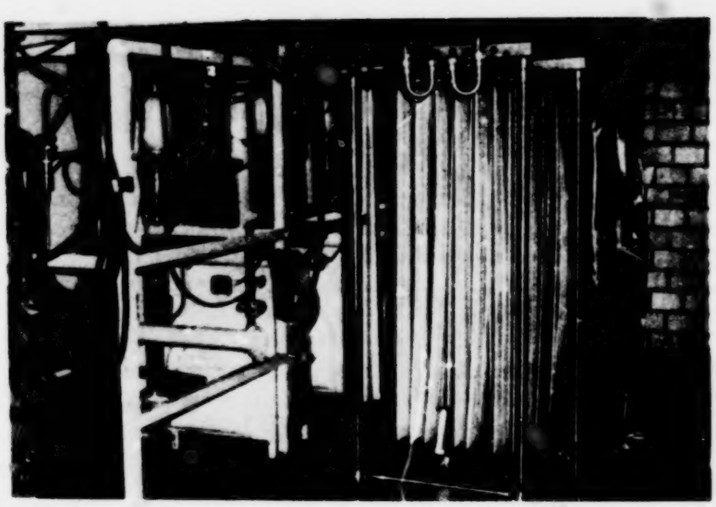


Figure 7
Pilot Plant
Reverse Osmosis Section Modules

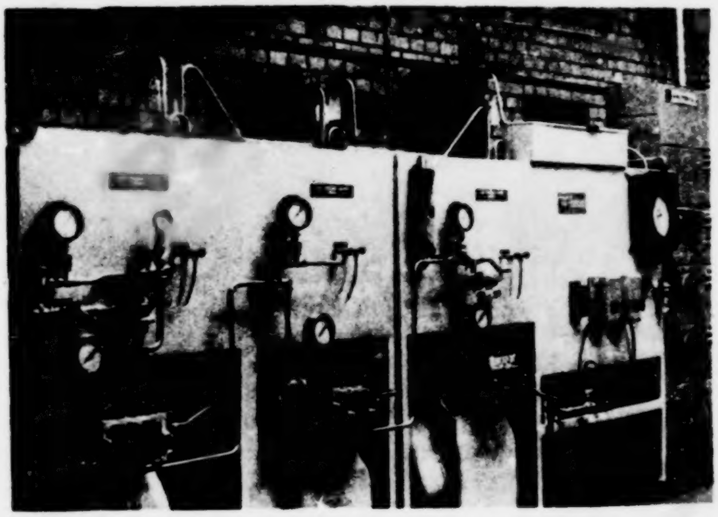


Figure 8
Pilot Plant
Reverse Osmosis Section Control Panels

The system design proved to be sanitary and produced products with microbiological counts suitable as food or dairy products. Details of the operation of the pilot plant are presented below.

Sampling and Analytical Procedures

Analyses listed in Table 2 were performed on a regular basis.

Table 2. Analyses used for Pilot Plant Program

Analysis	References
COD (Frequently calibrated with standard glucose solutions)	
BOD	
Kjeldahl Nitrogen	Standard Methods: Water and Wastewater, 12th Edition, 1965.
Total Solids	Standard Methods: Dairy Products, 12th Edition, 1965.
Acidity (Lactic Acid)	
Fat	
Conductivity	

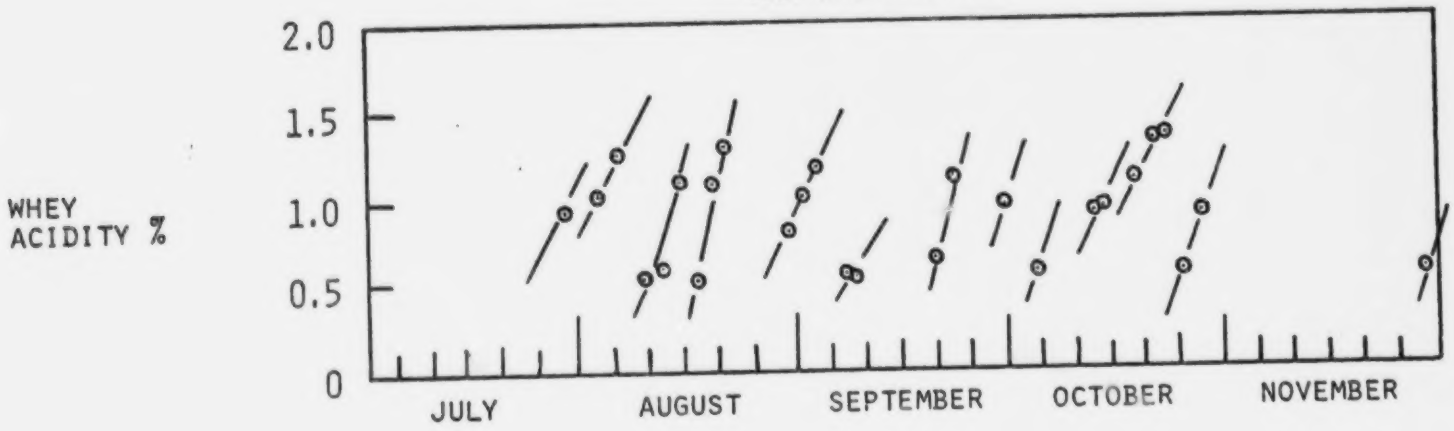
Ultrafiltration Section

Procedure. All the experiments described involved unfiltered cottage cheese whey. The whey was stored warm until used, with the storage temperature ranging between 110 and 120°F. With this storage procedure, operation was with whey with an acidity ranging between 0.5 and 1.3 percent (expressed as lactic acid). This is evident from the data in Figure 9. Whey was generally received with an acidity of about 0.5 percent (see August 10, and 17, September 7, October 5 and 25, and November 30). In the course of two to five days, the whey acidity increased substantially. As will be shown in the discussion of the RO data, this increase in acidity led to an increase in the effluent BOD. This relates to the fact that lactic acid is only moderately retained by RO membranes.

Batch operation was performed according to the following procedure. After a run, the membrane system was cleaned with AlcoZyme (Alconox, Inc.) at a concentration of 1/2 oz/gal, according to procedures developed in prototype experiments. After cleaning, the system was flushed with water and stored

FIGURE 9

RAW WHEY ACIDITY



until the next experiment. Immediately before startup, the system was sanitized with a solution of Antibac B (Wyandotte Chemicals Corp.) at a concentration of 1/12 oz/gal.

Following flushing with whey, a small storage tank and the UF system were filled with raw whey. Upon startup, whey was concentrated either for a given period of time or until a given volume of whey had been processed. During this period the small storage tank was kept full by the addition of fresh whey. At a preselected time or whey concentration, the supply of fresh whey to the small storage tank was shut off. At this point, the system contents were concentrated until the capacity of the small storage tank was exhausted. This latter operation is referred to as "cook-down".

Dependence of Flux on Protein Concentration. In Figure 10 are presented data for flux as a function of the retained protein concentration. The data presented are for runs on four days. The runs of October 10 and 22 were performed with whey of a high acidity. In addition, during the run of November 30, at high protein concentrations some acidification occurred in the whey. It appears on the basis of these data, as well as general observations on pilot plant performance (not discussed here), that somewhat lower fluxes were observed with high acidity whey. Also shown in Figure 10 are the temperature profiles for the runs.

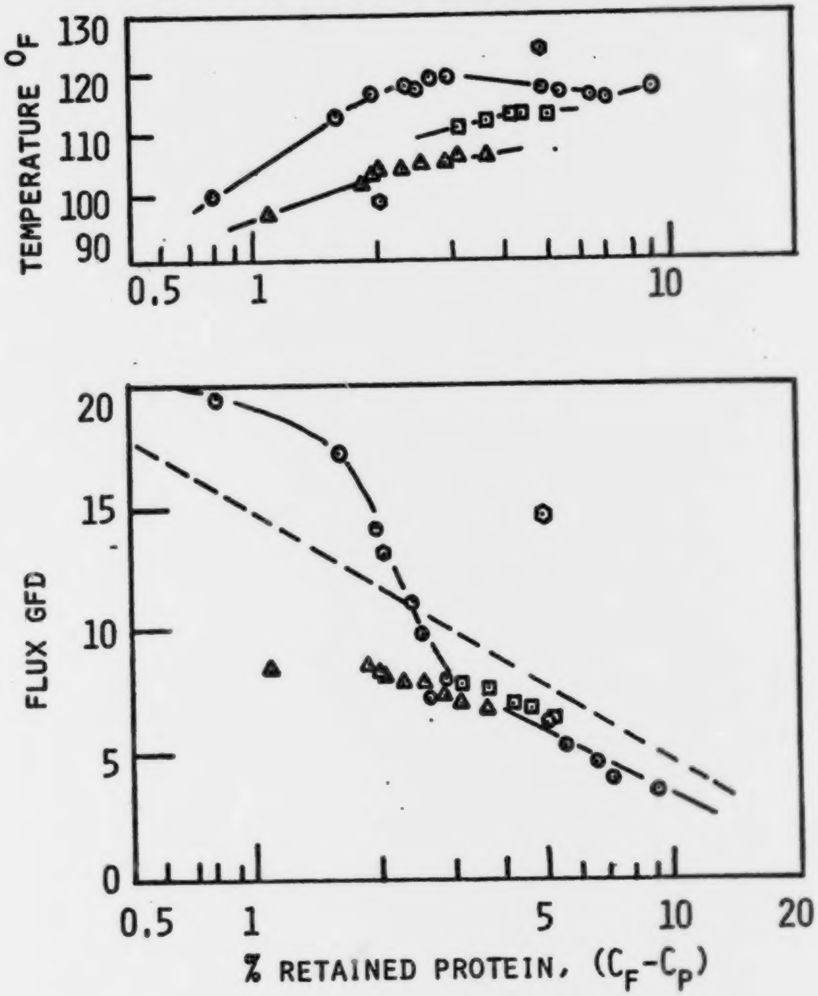
Flux decreased with increasing retained protein concentration, as expected. Data are comparable to prototype data which are also shown (120°F and 13.5 gpm).

Dependence of Flux on Time (Life Data). In Figure 11 are shown flux data for the pilot plant during the 4 1/2 months of operation. In the bottom plot is shown an average flux for batch operation, to an average concentration ratio (shown in middle plot) at an average temperature (shown in the upper plot).

The average concentration ratio is the concentration ratio up to the point of cook-down, and the average temperature is the temperature during this operation. In general, scatter in average flux up to cook-down can be related to variations in the concentration ratio and operating temperature. Higher fluxes are correlatable with lower average concentration ratios and higher operating temperatures. The most striking observation that can be made from the data of Figure 11 is that flux was virtually unchanged over the entire pilot plant operation. A mean average flux for a four-fold concentration ratio was 14 gfd at about 108°F.

Additional flux data for the entire batch concentration, including cook-down, are shown in Table 3. Shown are the date of operation, the protein concentration obtained in the final concentrate, the total solids content of the final concentrate, the percent protein on a dry solids basis, the average flux, and the operating temperature.

FIGURE 10
PILOT PLANT ULTRAFILTRATION DATA
EFFECT OF FEED CONCENTRATION ON FLUX



⊙ RUN OF 11/30/70
⊡ RUN OF 10/19/70
▲ RUN OF 10/22/70
⊙ RUN OF 7/22/70
15.5 GPM RECIRCULATION RATE
INLET PRESSURE ≈ 60 PSIG;
OUTLET PRESSURE ≈ 20 PSIG
-------PROTOTYPE DATA
(120°F, 13.5 GPM)

FIGURE 11

PILOT PLANT ULTRAFILTRATION DATA WHEY FLUX VS. TIME

(15.5 GPM CIRCULATION RATE:
INLET PRESSURE 60 PSI; OUTLET PRESSURE 20 PSI)

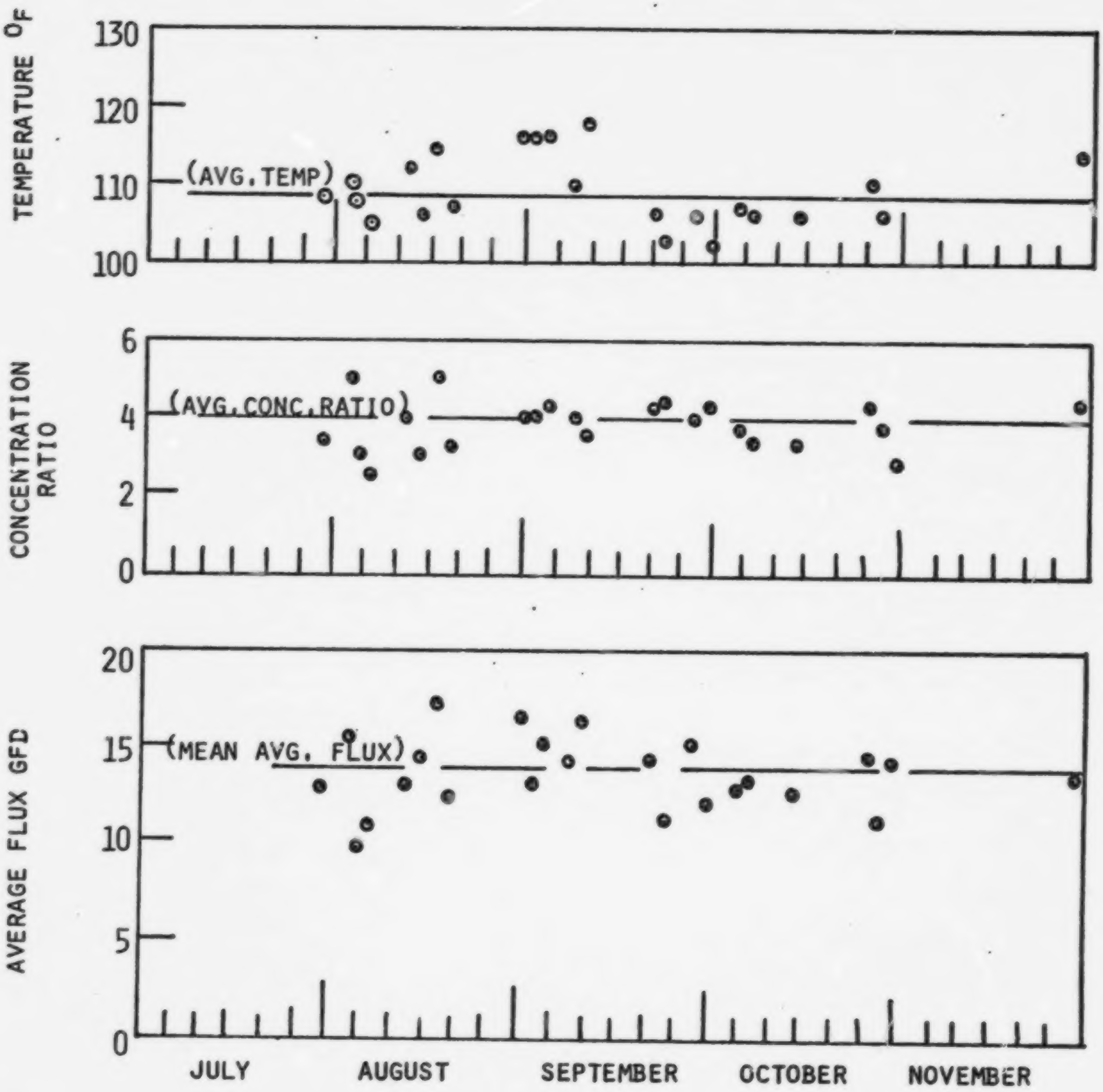


Table 3. Pilot Plant Ultrafiltration Data

Date	Final Protein Concentration	Final Total Solids	Protein (dry basis)	Average Flux (gfd)	Average Temperature
8/3	8.1%	14.6%	55.5%	14.4	110°F
7/29	6.4	12.9	50	10.7	100
8/17	14.6	21.1	69.5	13.7	114
9/31	8.3	15.5	53.5	14.5	112
11/30	9.3	15.8	59	13.0	114

Concentrates with protein percentages between 50 and 70 protein were generated, and average fluxes ranged between 10.7 and 14.5 gfd. On the basis of the data of Figure 11 and Table it is concluded that the capacity of the UF section of the pilot plant remained constant during pilot operation.

Membrane Retention Properties

Retention properties of the ultrafiltration membranes have been determined for all major whey components. These are listed in Table 4.

Table 4. Retention of Whey Components in Ultrafiltration

Component	Retention (%)
True Protein (Based on gel permeation chromatography analysis)	98+
Fat	>90
Lactic Acid	10-20
Lactose	0
Minerals	0
Non-Protein Nitrogen	0

It can be concluded that the ultrafiltration membranes exhibited excellent fractionation properties. Retained fat and lactic acid probably existed in the whey as protein complexes and were therefore retained in the concentrate.

Since these data were obtained at the end of the pilot program and since no changes were made in the UF section during the program, it is concluded that protein retention and fractionation were excellent throughout the pilot program.

Reverse Osmosis Section

Procedure. All RO experiments except one with whole whey were performed with ultrafiltration permeate. Operating procedure involved cleanup by flushing with tap water until the system was well purged. Following storage but before startup, the system was sanitized with Antibac B at a concentration of 1 oz/120 gal, and purged with UF whey-permeate.

Results for oxygen demand have been expressed in terms of COD, which was the analysis generally performed. Separate analyses on a variety of samples (raw whey, UF permeates, RO permeates) indicated the BOD_5 level to be about 50 percent of the COD level.

Dependence of Flux and Rejection on Feed Concentration. Flux and COD rejection were determined as a function of feed concentration level. Data for a batch experiment are shown in Figure 12. Flux as a function of feed concentration, expressed as COD or approximate total solids, is shown in the upper curve. In the lower figure, COD levels in the permeate are given, and in the middle graph, COD rejection.

These data show an expected decline in flux with increasing feed concentration. COD rejection was excellent, ranging from 98.5 to 99 percent. Based on these data, the mixed permeate for a four-fold volumetric concentration would have a COD level of approximately 1,250 mg/ℓ. This corresponds to a BOD_5 level below 700 mg/ℓ.

In general, somewhat higher flux levels were observed during the pilot program. Figure 13 shows data for flux recorded during the period from July 22, through October 21, 1970. Data points are shown for continuous operation in three different temperature ranges. Numbers in parentheses near data points indicate approximate operating pressure. It is apparent that both increases in operating temperature and pressure resulted in increases in flux.

The data have been scaled-up to an operating pressure of 750 psi in Figure 14. The scale-up factor is based solely on the ratio of operating pressures; that is, fluxes are multipled by (750/operating pressure). This is a conservative scale-up factor, since it neglects the osmotic pressure of the feed, which is an important consideration especially at higher feed concentrations. The data in Figures 13 and 14 are considered to be an accurate indication of the flux-concentration profile observed in the pilot plant program.

No trend in the data could be related to length of operating time covering a four-month period, and on this basis it is concluded that negligible membrane compaction occurred. This is confirmed by the absence of a decline in membrane water flux (data not reported here) during the pilot program.

FIGURE 12

PILOT PLANT

REVERSE OSMOSIS DATA

RUN OF 8/31/70 (WHEY ACIDITY = 0.8%)

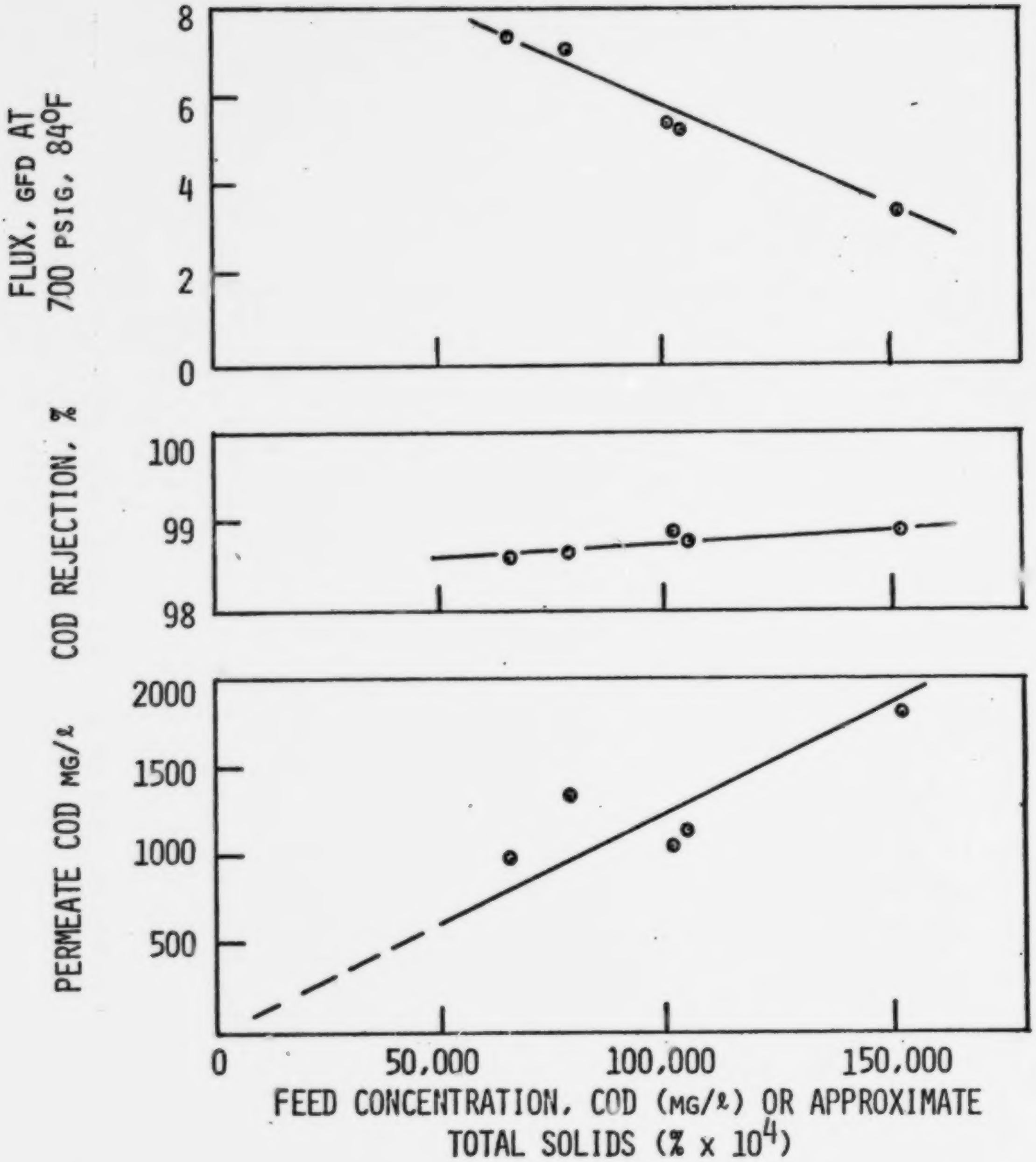


FIGURE 13

PILOT PLANT REVERSE OSMOSIS DATA

EFFECT OF FEED CONCENTRATION ON FLUX

(DATA FROM 7/22 THROUGH 10/30)

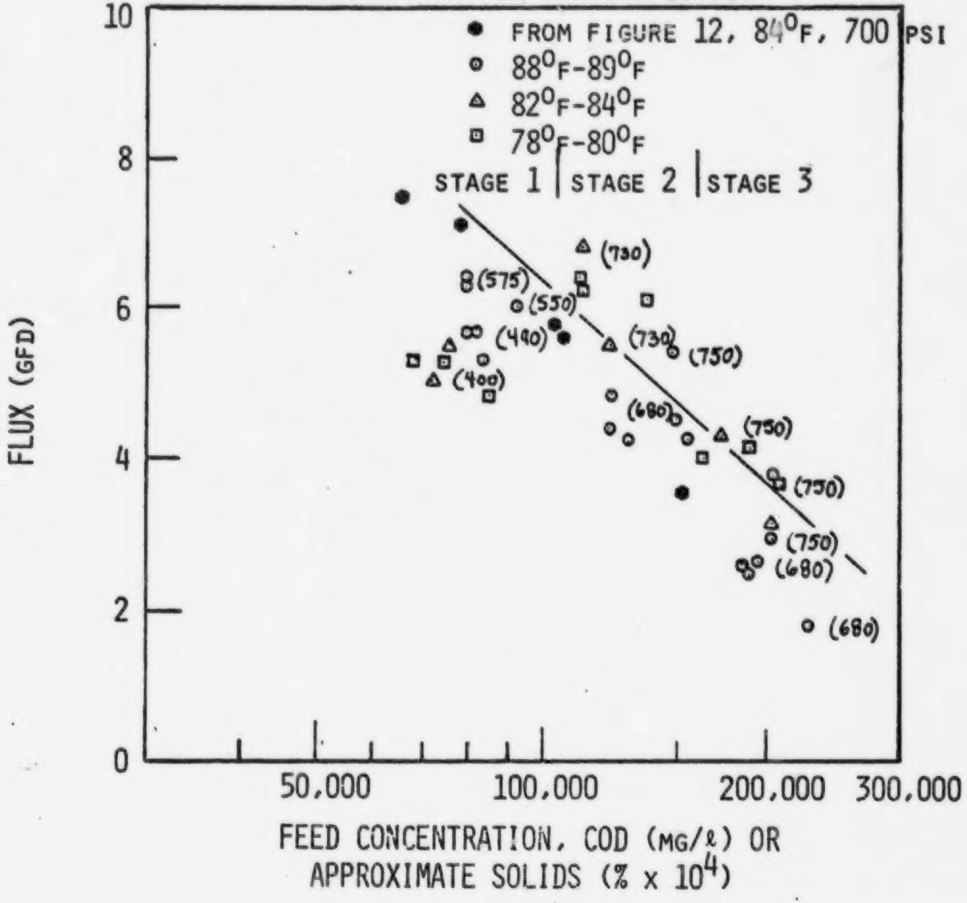
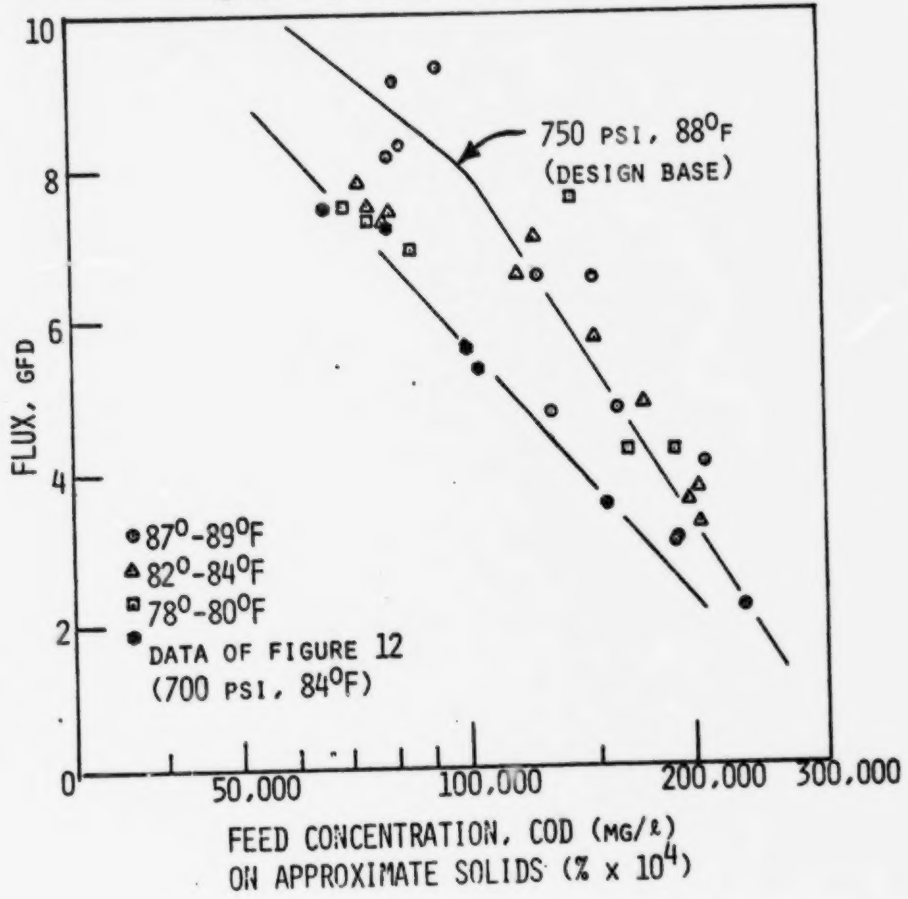


FIGURE 14

PILOT PLANT REVERSE OSMOSIS DATA

EFFECT OF FEED CONCENTRATION ON FLUX

(DATA FROM 7/22 THROUGH 10/30)



Based on these data, a very conservative average flux for concentration of UF permeate from 6 percent to 25 percent solids is 5.5 gfd, and this value has been chosen as the design basis for the demonstration plant.

Lactic Acid Rejection. Pilot data showing lactic acid rejection are given in Figure 15. Shown in the lower plot is the level of lactic acid in the permeate as a function of the lactic acid in the feed. From the upper plot, rejection is observed to be in the range of 60-70 percent. On the basis of these and prototype data it is apparent that substantial lactic acid passes through RO membranes, and this contributes appreciably to the level of BOD in the final effluent.

Effect of Time on Rejection (Life Data). In Figure 16 overall oxygen demand reduction data are presented for the pilot operation. Mixed permeate (final effluent) COD and BOD levels are shown as a function of time. Also given are the operating pressure and the feed whey acidity.

On July 22, the first day of operation, the effluent COD was about 4000 mg/ℓ, corresponding to a BOD of about 2000 mg/ℓ. This was followed by a period during which performance was unsatisfactory. This was related to visually observable module leaks (riboflavin appeared in the permeate, giving a green color). However, following the installation of a few new modules, at the beginning and toward the end of September, COD rejection became excellent. After the second replacement, performance continued to be excellent through the end of November (the end of the pilot program), at which time COD rejection for all modules exceeded 97.5 percent.*

During this last portion of the program, variation in oxygen demand of the effluent (mixed permeate) was related primarily to the whey acidity. Higher acid levels resulted in higher effluent oxygen demand. BOD levels, on days when low-acidity whey was used, were in the range 1,000 to 1,500 mg/ℓ. This corresponds to an overall BOD reduction of 96-97 percent, based on raw whey BOD of 35,000 mg/ℓ.

It is expected that operating pressure also played an important role, although these data do not indicate any marked effect.

Earlier losses of rejection efficiency were due to the development of leaks in a few modules. This is demonstrated by the data of Table 5, which gives rejection data on Sept. 10 for a sampling of modules. It is apparent that the bulk of the modules had acceptable to excellent rejection. One module had a gross leak; two had smaller leaks; and one was "off-spec".

At the end of the program, about 75 percent of the initial modules were still in operation, and these had demonstrated a usable life of 4 1/2 months without detectable deterioration in flux or COD rejection.

---

*Rejection is defined as $\frac{COD_{Feed} - COD_{permeate}}{COD_{Feed}}$ X 100 at a given feed concentration. Reduction may be defined as $\frac{COD_{Raw\ Whey} - COD_{Mixed\ Permeate}}{COD_{Raw\ Whey}}$ X 100 and will always be less than "point" rejection values.

FIGURE 15
PILOT PLANT
REVERSE OSMOSIS DATA
LACTIC ACID REJECTION
RUN OF 8/14/70

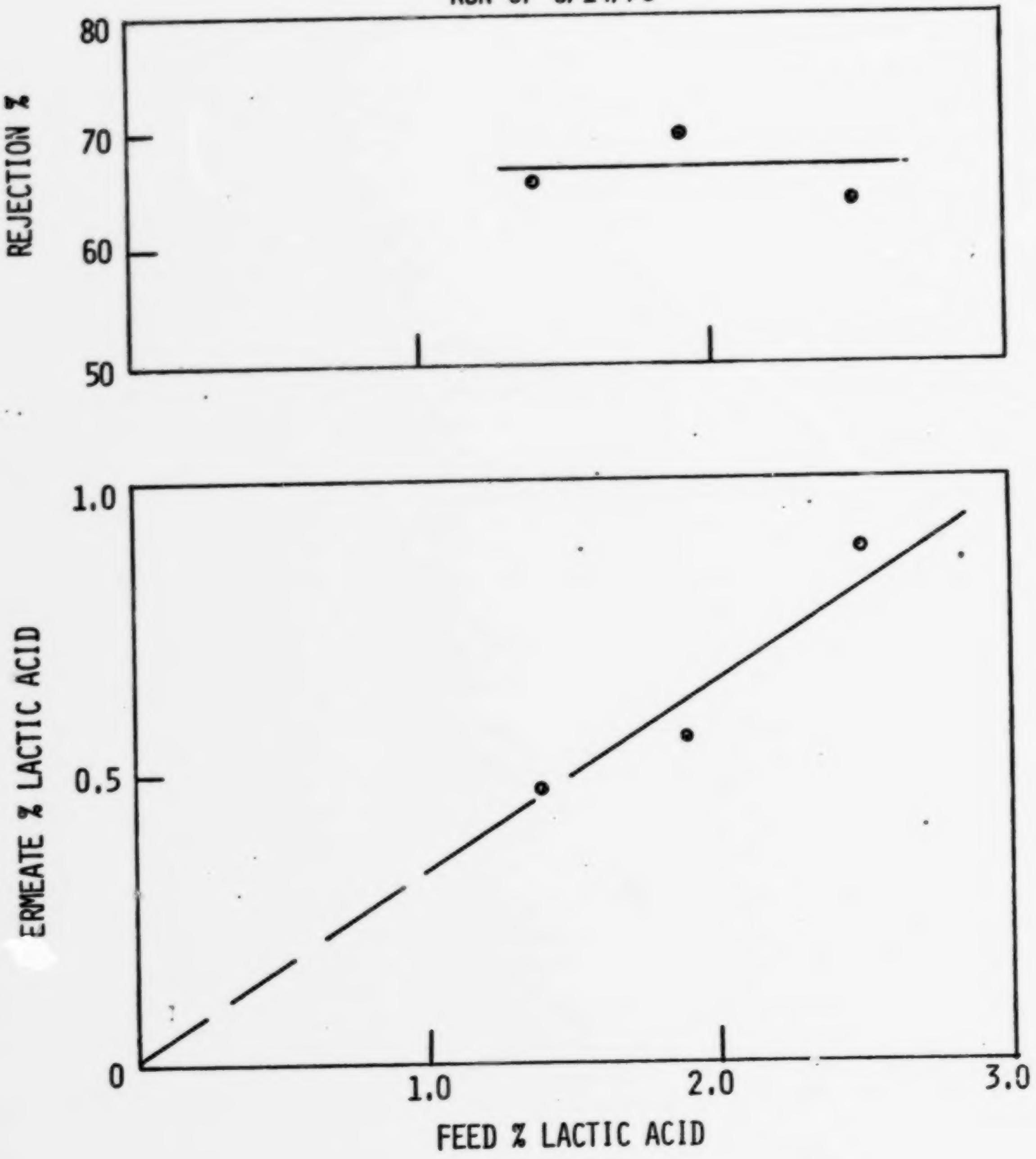


FIGURE 16
REVERSE OSMOSIS DATA
PILOT PLANT OXYGEN DEMAND REDUCTION
(RAW WHEY COD = 65,000 MG/ℓ; BOD = 35,000 MG/ℓ)
(≈ 4-FOLD CONCENTRATION TO 22-25% SOLIDS)

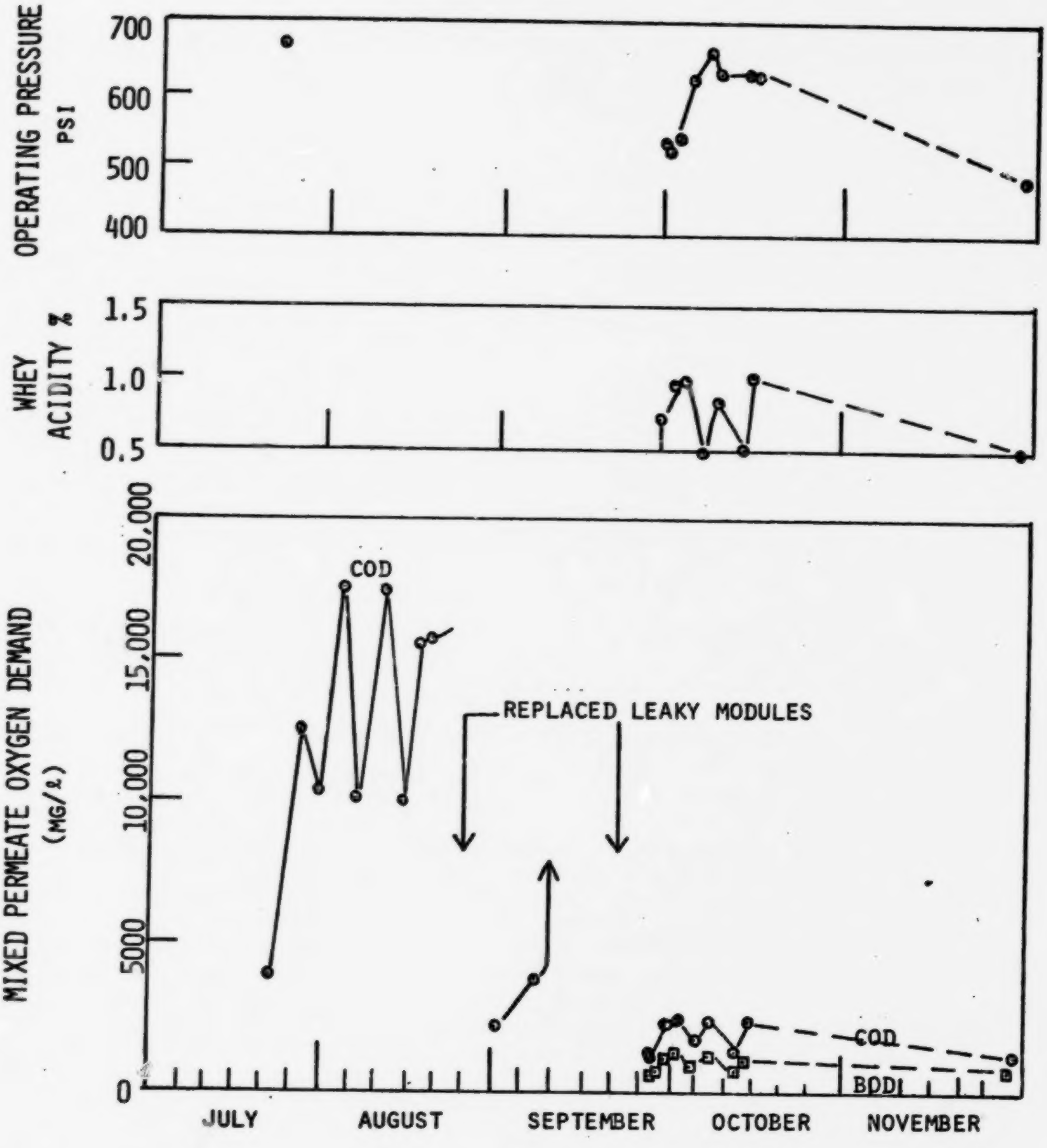


Table 5 COD Rejection Distribution of Modules

Module #	COD Rejection, %	Observations
1	99.3	
2	99.2	
3	99.2	
4	99.0	good rejection
5	99.0	
6	98.9	
7	98.8	
8	98.7	
9	98.3	
10	98.3	
11	98.1	acceptable rejection
12	97.3	
13	97.3	
14	96.5	
15	91.6	"OFF. SPEC.", unacceptable
16	86	leak,
17	84	leak,
18	50	gross leak

Concentration of Whole Whey. In a single experiment, raw cottage cheese whey was concentrated in the RO section, and flux and rejection were comparable to values obtained for the concentration of UF permeate. Similar results were obtained in several prototype experiments. One marked difference between performance with whole whey and UF permeate relates to the ease of system clean-up. As will be seen in the microbiological data below, when UF permeate was processed in the RO section, clean-up and sanitizing was relatively simple and effective. However, in the experiment with whole whey, substantial difficulty was encountered in clean-up. Probably the presence of residual casein fines as well as the whey proteins contributed to both system fouling and the accumulation of solids at system dead-ends. On the other hand, UF permeate is deproteinized and contains no suspended solids. Lactose, salts and the residual low molecular weight organics have high solubilities and can be removed from the system simply by flushing with water. This difference between concentrating whole whey and UF permeate by RO appears to be quite important, in that currently available RO equipment is often difficult to clean. Processing of UF permeate removes this process limitation.

MICROBIOLOGICAL DATA

During the course of the pilot-plant program, samples were analyzed for total viable bacteria and coliforms. In Table 6 are given the data for different test dates. The dates run from the end of July through the beginning of October. In the second column are given the dilution ratios for the samples before culturing. The other columns give counts for raw whey, UF concentrate, UF permeate (in interstage tank), RO feed (from RO modules), the final lactose concentrate, and the RO permeate.

Several observations can be drawn. First, at no time did the counts for either total viable bacteria or coliforms in the protein concentrate exceed the level for Grade A milk (50,000 org/ml). This was the case even though counts in the feed whey sometimes exceeded this level (see data for July 31, August 18, September 29, and October 5).

Evidently, operation in the UF section at 110-120°F for several hours did not lead to bacteriological growth. In fact, in certain cases it appeared that decreases in plate counts were observed. These data confirm the previously obtained prototype data which indicate that growth of microorganisms in cottage cheese whey is not a factor of major importance(9).

In general the UF permeate, sampled in the interstage tank, also had low total plate counts. There were some exceptions however, which are attributed to improper cleaning. Although the counts on August 14, September 29 and October 1 were high, proper cleaning of the system resulted in a return to low counts. (See for example, data of August 18 and October 5.)

The feed to the RO section was taken from the interstage tank. Correspondingly, on days when the UF permeate was contaminated (August 14, September 29 and October 1), the feed to the RO section was also contaminated. This explains the high counts on the same dates in the RO feed samples. Additional data for October 12 and October 28 showed contamination of the high pressure section even though the UF permeate had low counts. This is thought to be due to the fact that no sanitizer was used in the RO system on those days.

In general, plate counts for the lactose concentrate followed the counts for the feed to the RO system. At times, however, counts in the lactose concentrate were higher than in the RO system (e.g., July 29), and this is thought to be due to the use of a Tygon tube to drain off the lactose concentrate. The tube ran only partially full, and microbiological growth was observed on the tube's inside surface. Proper cleaning and sanitizing of the tube was not possible.

Table 6 Total Plate Counts and E. Coli Counts

DATE	DILUTION	RAW WHEY		UF CONCENTRATE		UF PERMEATE		RO FEED		LACTOSE CONCENTRATE		RO PERMEATE	
		TPC	E.COLI	TPC	E.COLI	TPC	E.COLI	TPC	E.COLI	TPC	E.COLI	TPC	E.COLI
7/29/70	1/1000	12,000	<1	20,000	<1	14,000	<1	4,000	<1	46,000	<1		
	1/10,000	20,000		30,000		10,000		<10,000		30,000			
7/31/70	1/1000	41,000	<1	2,000	<1	1,000	<1	4,000	<1	2,000	<1		
	1/10,000	111,000		<10,000		<10,000		20,000		40,000			
8/10/70	1/1000					67,000	3			100,000	3	51,000	<1
	1/10,000					90,000				140,000		80,000	
8/12/70	1/1000	<30,000	<1	<30,000	<1	<30,000	2	36,000	40	160,000	<1	81,000	<1
	1/10,000	30,000		5,000		30,000		40,000		110,000		50,000	
8/14/70	1/1000	<3,000		<3,000		780,000		650,000		650,000		18,000	
8/18/70	1/1000	585,000	<1			11,000	<1	17,000	12	143,000	<300	131,000	<1
	1/10,000	440,000				10,000		30,000		70,000		150,000	
9/2/70	1/1000	<3,000	<1	<3,000	<1	<3,000	<1	6,000	<1	<3,000	<1	5,000	<1
	1/10,000	<30,000		<30,000		<30,000		<30,000		<30,000		<30,000	
9/29/70	1/1000	520,000	<1	13,000	<1	190,000	<1	460,000	5	460,000	4	7,000	<1
	1/10,000	370,000		20,000		230,000		380,000		240,000		10,000	
10/1/70	1/1000	<30,000	<1	<30,000	<1	140,000	<1	120,000	<1	110,000	<1	150,000	<1
	1/10,000	<30,000		<30,000		180,000		160,000		140,000		240,000	
10/5/70	1/1000	78,000	<1	21,000	<1	4,000	<1	17,000	<1	48,000	<1	20,000	<1
	1/10,000	100,000		30,000		10,000		40,000		140,000		20,000	
10/12/70	1/1000	<1,000	<1	13,000	<1	21,000	6	220,000	<1	520,000	<1	20,000	<1
	1/10,000	<10,000		40,000		10,000		210,000		540,000		10,000	
10/28/70	1/1000	4,000	<1	<1,000	<1	41,000	<1	300,000	<1	52,000	<1	92,000	<1
	1/10,000	10,000		<10,000		50,000		340,000		50,000		70,000	
11/7 & 9/70				<10,000	<1	10,000	<1	<10,000	<1	<10,000	0		

Microorganism counts in RO permeates are based on samples taken from the module permeate collection pans. These were generally not washed or sanitized, accounting for the relatively-high levels of microorganisms on many dates. On days when the system was well sanitized (see for example, September 2), however, counts in the permeates were low.

Samples from all sampling points, except for the UF concentrate, showed contamination at some time. It is to be noted that proper cleaning and sanitizing was very effective in lowering these counts. Observe the data of October 5, which show very low counts, approaching levels for grade A milk. Similar results are seen for September 2.

The final entry in the table gives representative data for an experiment conducted over several days. At the end of the run on October 28, the system was cleaned and sanitized. At this time it was filled with water, which was sampled over a period exceeding one week. Bacteria counts for the system for November 7 and November 9 are shown, indicating the presence of very few residual microorganisms.

It is concluded, therefore, that not only was the system design satisfactory from the point of view of sanitation, but also that the system could be stored for at least one week in water without substantial microbiological contamination.

FULL-SCALE PLANT

During 1971 a 250,000 lbs cottage cheese whey/day treatment facility will be built and installed at Crowley's LeFargeville, New York location facility. Based on the pilot plant data, capital and operating costs have been developed.

CAPITAL COSTS

Capital cost items are given in Table 7. Costs for the ultrafiltration and reverse osmosis sections are $180,000 and $310,000 respectively. Six tanks will be required. This includes three 10,000 gallon tanks for raw whey storage (one-day capacity). One 5,000 gallon surge tank will be needed for the UF permeate (feed tank for the RO section). Two CIP tanks will be needed for storage of cleaning and sanitizing solutions. Total costs for the tanks, inlcuding piping and valves, is projected to be $50,000.

Additional capital costs include $40,000 for installation, and $30,000 for a building to house the plant. Total capital costs for the plant are projected to be $610,000.

Table 7 Projected Capital Costs for 250,000 lbs. Whey/Day Plant:

Equipment	
Ultrafiltration Section	$180,000
Reverse Osmosis Section	310,000
Tanks	
3 - 10,000 gals. plastic silos for whey storage (1 day capacity)	
1 - 5,000 gals. UF permeate surge tank	
2 - CIP tanks for storage of cleaning and sanitizing solutions	
Total for 6 tanks with piping and valves	50,000
	540,000
Installation Costs	40,000
Building Costs (3000 ft.^{2})	30,000
TOTAL CAPITAL COSTS	$610,000

OPERATING COSTS

Operating costs are shown in Table 8. Among the items listed, costs for power and cooling water are based on actual operating data from the pilot plant. The membrane equipment itself, has been depreciated on two bases. Membrane modules, less the annual charge for membrane replacement, have been depreciated over five years. The associated membrane hardware (pumps, valves, controlls, etc.) have been depreciated over ten years, as has been the remaining capital cost items.

The annual operating costs will be approximately $196,000.

PROJECTED BY-PRODUCT VALUES AND PROCESS PROFITABILITY

Fractions obtained from the membrane process have useable characteristics. In treating 80,000,000 lbs. of cottage cheese whey per year, 480,000 lbs. of protein (at 0.6 percent in whey) and 3,600,000 lbs. of lactose (at 4.5 percent in whey) will be recovered. The value for these by-products when used as food ingredients will be sustantial in dollars. The net annual profit, the difference between income and operating expenses, is expected to show a highly favorable return on investment.

CONCLUSIONS AND RECOMMENDATIONS

Membrane processes offer an economically attractive solution for waste treatment of cottage cheese whey. Pilot operation has shown that a two-step

Table 8 Projected Operating Costs for 250,000 lbs. Whey/Day Plant:

Basis: 320 days/yr or 7680 hrs/yr

Labor and Overhead	
Supervisory 3 hrs/day x 320 days/yr @ $5.00/hr	$ 4,800
Plant Operator 7,680 hrs x $3.00/hr	23,040
Lab tester 2 hrs/day x 320 days/yr @ $3.00/hr	1,920
Mechanic 1 hr/day x 320 days/yr @ $4.00/hr	1,280
	$31,040
Fringe and overhead @ 40 percent of wages	12,400
Total Labor	$43,440
Annual Membrane Replacement cost at 5 $/ft^2	33,400
*Power @ 1.2 ¢/kwh	5,000
*Cooling Water	4,000
Steam	3,000
Cleaning Chemicals (10 $/day)	3,200
Disposables (e.g., pump, gaskets, seals, etc.)	3,200
Professional Services (outside maintenance costs, engineering services, consultants)	10,000
Interest and Taxes @ 3 percent of Capital	18,300
Depreciation	
Membrane Modules ex membranes @ 20 percent	32,500
Membrane process hardware (pumps, valves, etc.) @ 10 percent	27,000
Remaining Capital Items @ 10 percent	12,000
Projecting Annual Operating Costs	$195,540

*Actual costs based on scale-up of pilot plant utility usage.

process successfully produces protein concentrates through whey fractionation and a high concentration lactose concentrate through reverse osmosis. The BOD of raw cottage cheese whey can be reduced from approximately 35,000 mg/1 to less than 1,000 mg/1 by membrane processing. Protein concentrates containing up to 20 percent protein (80 percent protein on dry solids basis) can be generated in a single step ultrafiltration. Lactose concentrates containing 20 percent lactose (75 percent lactose on a dry solids basis) can be generated by concentration through reverse osmosis of the ultrafiltration permeate. Whole cottage cheese whey can be concentrated to about 25 percent solids by reverse osmosis without prior deproteinization (by ultrafiltration or otherwise). Products produced from the two-step membrane process, protein and lactose concentrates, have low total plate counts and nil coliform counts. Products produced in the pilot plant operation met standards for Grade A milk. Concentration of whole whey by reverse osmosis is complicated by the difficulty of clean-up and sanitizing of the membrane equipment. Prior deproteinization of whey eliminates this problem. Installation and operation of a 250,000 lb/day plant are expected to yield a high return on investment before taxes, corresponding to a rapid plant pay-out. This conclusion incorporates both capital and operating costs, as well as information proprietary to Crowley's Milk Company regarding the utilization and value of protein and lactose products. Plant capital costs for a 250,000 lbs whey/day installation is projected to be $610,000; and annual operating costs, $196,000.

Crowley's Milk Company recommends the installation and operation of a 250,000 lbs cottage cheese whey/day membrane processing facility at the LeFargeville, N. Y. plant. This unit is to be constructed in Phase II of the program.

ACKNOWLEDGEMENTS

The support of the project by the Federal Water Quality Office and the help provided by Dr. William Lacy, Mr. George Keeler, and Mr. Allyn Richardson, the Federal Grant Project Officer, is acknowledged with sincere thanks.

REFERENCES

1. Kosikowski, Frank, "Greater Utilization of Whey Powder for Human Consumption and Nutrition", (Our Industry Today), J. Dairy Science, Vol. 50, No. 8, pp. 1343-1345, (1967).

2. Wix, P. & Woodbine, M., "The Disposal & Utilization of Whey, A review", Dairy Sci. Abstr., Vol. 20, pp. 537-567 and 625-634, (1958).

3. Marshall, P.G., Dunkley, W.L., Lower, E., "Fractionation and Concentration of Whey by Reverse Osmosis", Food Technology, Vol. 22, No. 8, pp. 37-44, (August, 1968).

4. McDonough, F.E., "Whey Concentration by Reverse Osmosis", Food Engineering, Vol. 40, No. 3, March 1968.

5. Anonymous, "USDA Studies Reverse Osmosis as Whey Disposal Method", New Release No. USDA 1396-68, Washington, D.C., May 1, 1968.

6. B.S. Horton, R.L. Goldsmith, S. Hossain and R.R. Zall, "Membrane Separation Processes for the Abatement of Pollution from Cottage Cheese Whey", presented at the Cottage Cheese and Cultured Milk Products Symposium, University of Maryland, (March 11, 1970).

7. B.S. Horton, "Prevents Whey Pollution Recovers Profitable By-Products", Food Engineering, Vol. 42, No. 7, pp. 81-83 (July, 1970).

8. B.S. Horton, R.L. Goldsmith, S. Hossain and R.R. Zall, "New Method for Economical Control of Pollution Caused by Cheese Wheys", presented at SOS/70, Washington, D.C., (August 14, 1970).

9. R.L. Goldsmith, et al., "Recovery of Cheese Whey Proteins through Ultrafiltration", presented at SOS/70, Washington, D.C., (August 14, 1970).

ACTIVATED SLUDGE AND TRICKLING FILTRATION TREATMENT OF WHEY EFFLUENTS

by

Thomas P. Quirk* and Joseph Hellman*

INTRODUCTION

The processing and manufacturing of dairy products is one of the most widespread industries in the United States. More than 20 million cows produce over 100 billion pounds of milk yearly. A portion of the production is manufactured into cheese and other dairy products. Manufacturing operations are located in small communities in or near the rural milk production areas. Waste waters from milk operations are characterized by high putrescibility and high oxygen demand.

Whey from the manufacture of soft (cottage) or hard cheese contains high concentrations of BOD (30,000 to 50,000 mg/1), and total solids (50,000 to 72,000 mg/1), while relatively low in volume.

These concentrations, if discharged to a municipal sewerage system without adequate control, may easily upset the treatment process particularly if slugging occurs.

Whey rapidly exerts its oxygen demand causing septicity; lowers pH in the primary settling tank and primary digester; produces a substantial increase in sludge volume and can seriously reduce the performance of biological treatment processes.

Recovery by evaporation and drying is the most satisfactory solution to the problem of waste whey. The recovered whey solids may be incorporated in foods, or in feeds, or may be used for the manufacture of by-products. However, recovery is a fractional proposition that misses about one-fifth of the production which escapes as dilute rinse water.

When dairy processing operations are located in small communities, the industrial waste may contribute more organic load than the entire domestic population. Under such circumstances, domestic sewage treatment design criteria become inapplicable for sizing facilities to treat a combined effluent.

The Breakstone Foods Division of Kraftco maintains a large cottage cheese manufacturing operation at Walton, New York. Considerations

---

*Quirk, Lawler & Matusky Engineers, New York, N. Y.

relative to available land area indicated joint treatment of the sewage whey mixture. A project for the development of a suitable treatment process was undertaken.

The Village of Walton was awarded an EPA Research and Development Grant No. 11060 DUJ, for evaluation of packed tower trickling filtration treatment. Supplemental support to the project was provided by the Breakstone Foods Division of Kraftco. Prior studies using the activated sludge process were supported by Breakstone and the Village of Walton.

Previous Studies

Although waste treatment problems associated with whey bearing waste are frequently referenced in milk processing and waste treatment literature, there have been relatively few published studies of formal treatability investigations.

Wasserman(37) investigated the utilization of whey as a substrate for yeast culture. Optimum yeast yields, of 0.57 pounds of yeast per pound of lactose present, were obtained at pH 4.7 to 5.0, with supplementation of nutrient nitrogen.

The results of treatability studies with activated sludge have been reported by several authors. Jasewicz and Porges(17, 24) attributed the pronounced tendency of the culture to bulk to nutrient deficiencies that included nitrogen as well as other unspecified growth factors. Adamse(1) observed that process response was more rapid at pH 5 than in the more neutral range from pH 6 to 8.

Adverse experience was reported by Maloney et al(21) relative to the introduction of whey into sewage stabilization ponds. Culture changes, poor performance and odor evolution were attributed to the presence of whey in the influent waste.

Significant contributions to the waste treatment literature have been made relative to the application of biological filtration to the treatment of whey bearing wastes. Schulze(29,30,31) employed mesh screens for filter simulation and also observed culture growth characteristics.

Ingram(15,16) operated a deep rock filter pilot plant on whey bearing waste and advocated hydraulic loadings in excess of 1.0 gpm/SF to insure complete distribution and to maintain freshness. Results were obtained showing 67 percent BOD removal at an organic loading of 300 lb BOD/1,000 CFD. Under the prescribed operating conditions, odor problems were not encountered.

WASTE CHARACTERISTICS

A synthetic waste substrate was formulated for use in all laboratory studies. The waste substrate was prepared from Breakstone whey, settled sewage from the city of Yonkers, N. Y., skim milk and tap water in accord with the following formula:

Whey	1.55%
Skim Milk	0.09
Settled Sewage	15.90
Tap Water	82.40
	99.94%

The formula is a simulation of the waste mixture expected for design. Representative values of the COD, BOD and suspended solids for the trickling filter studies were 900, 650 and 100 ppm, respectively. Corresponding values for laboratory activated sludge study were 900, 750 and 45 ppm.

Table 1 presents a summary of characteristics of each effluent as used in pilot plant studies. Urea fertilizer was added to the waste as nitrogen supplement.

It is useful to segregate suspended and dissolved fractions of total BOD. The concept assists in the visualization of BOD removal by settling facilities and in the appraisal of the BOD contributions of effluent suspended solids losses. The results of determinations of BOD equivalency of the feed and effluent suspended solids from treatment of whey effluent are given in Figure 1. The BOD equivalencies for the suspended solids were 0.63 and 0.63 lb BOD/lb suspended solids, respectively, for feed and effluent.

Correlations between BOD and COD were sufficiently reliable to enable useful estimation of BOD from COD within the range of the data. Generally the BOD was about 60 percent of the COD. The COD remaining after total BOD removal is estimated at 50 ppm.

BOD-COD correlation relationships are shown on Figure 2.

EXPERIMENTAL FACILITIES

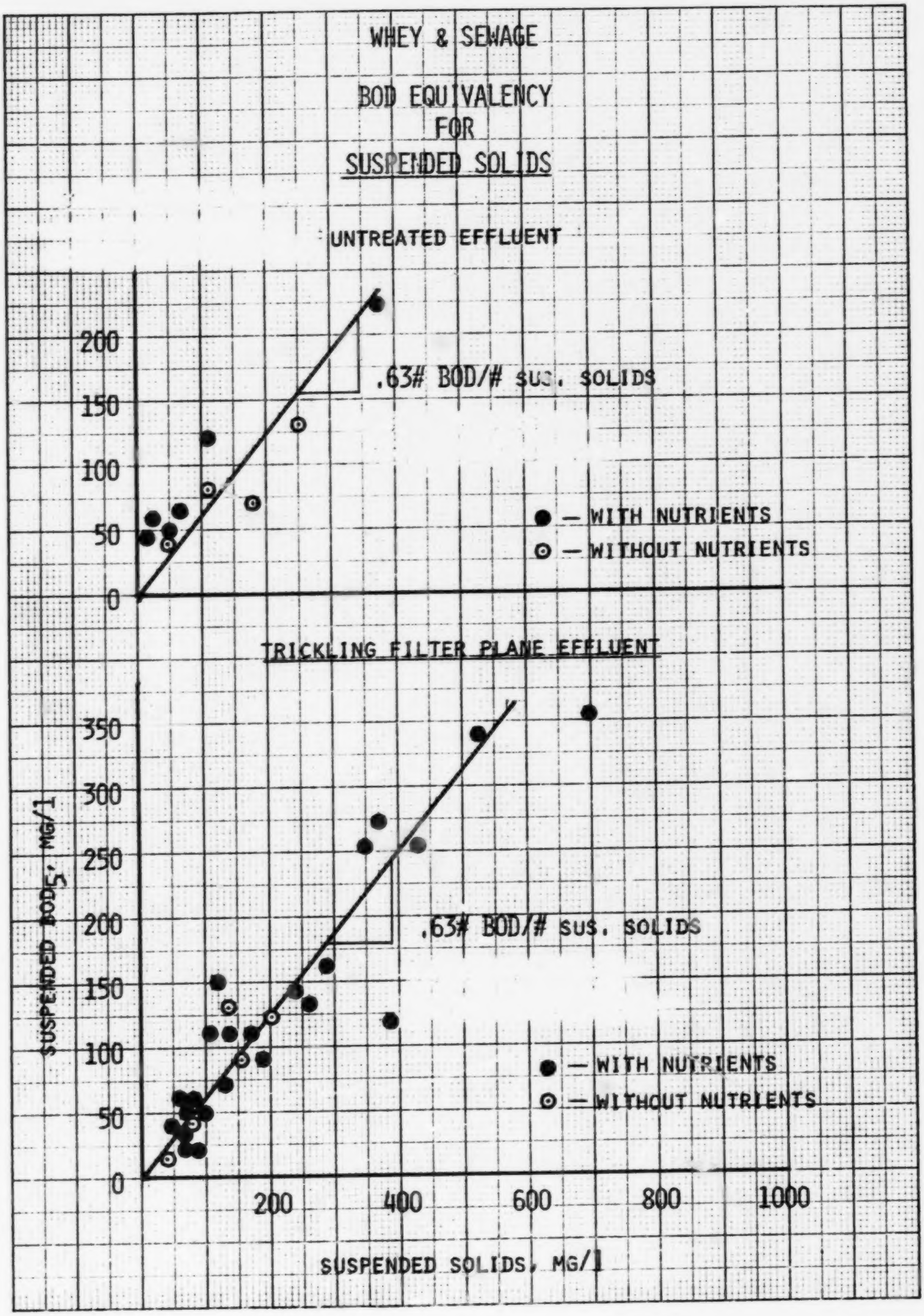
Experimental Scale

Sewage and industrial waste discharges are subject to pronounced hourly variations in flow, strength and characteristics. Under such unsteady conditions, the problem associated with the evaluation of the role of specific variables on process performance becomes greatly magnified. The evaluation of parameters can be effectively executed under controlled laboratory conditions enabling isolation of the effects of specific variables. These investigations employed laboratory techniques except where practical considerations as to scale dictated field studies. The evaluation of sludge dewatering characteristics was the principal area in which scale requirements dictated field studies. A summary of

Table 1. Characteristics of Pilot Plant Influent

Characteristics	Whey Effluent Aver.	Whey Effluent Range	Whey & Sewage Aver.	Whey & Sewage Range
Suspended Solids, ppm	240	770-41		
Total BOD ppm	830	1593-440		
Soluble BOD ppm	560	1075-170	241	310-172
Soluble BOD%	76			
Suspended BOD ppm	173			
BOD Equivalent of Suspended Solids	0.72			
Total COD ppm	1440	2390-840	451	595-307
Soluble COD ppm	841	1490-264		
Soluble COD%	74			
Suspended COD ppm	300			
COD Equivalent of Suspended Solids	1.25			
pH		5.5-7		6-7

FIGURE 1



WHEY & SEWAGE

BOD EQUIVALENCY
FOR
SUSPENDED SOLIDS

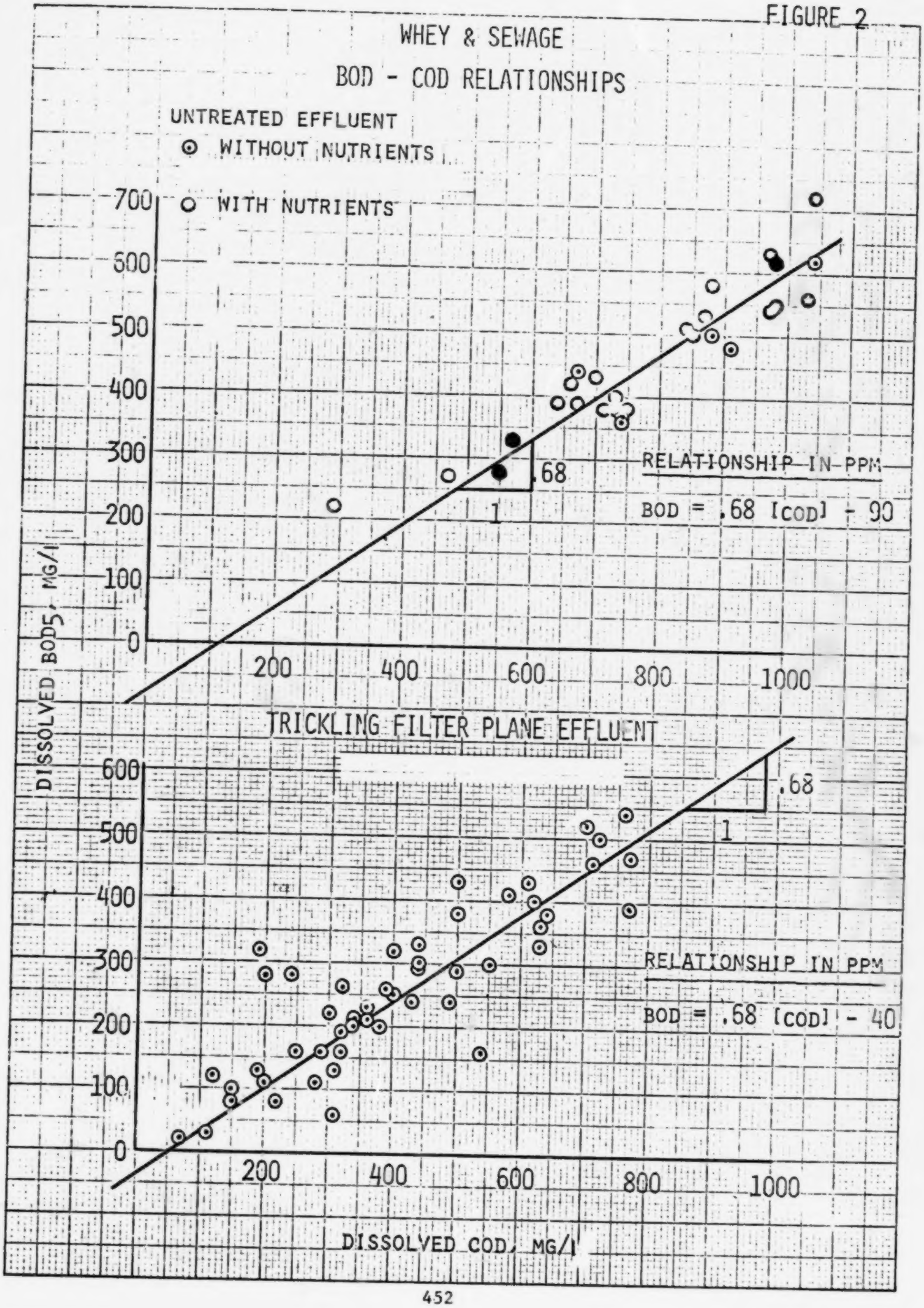
UNTREATED EFFLUENT

TRICKLING FILTER PLANE EFFLUENT

FIGURE 2

WHEY & SEWAGE

BOD - COD RELATIONSHIPS



experimental scale is shown on Table 2. Laboratory scale studies were conducted at QL&M laboratories. Field scale studies were conducted at Breakstone Foods.

Table 2. Biological Processes Investigated
Whey Plus Sewage

1. Processes	Experimental Conditions	
1. Fluid Bed Systems	Scale	Operation
A. Extended Aeration	Laboratory	Continuous
B. Contact Stabilization	Laboratory	Batch
C. Aerated Stablilization	Laboratory	Continuous
2. Fixed Bed Systems		
A. Trickling Filtration	Laboratory	Continuous
	Field	Continuous

Fluid Bed Facilities

Extended Aeration

The flow sheet for the **extended** aeration process consisted of a completely mixed aeration tank followed by a secondary clarifier. A major fraction of the underflow from the clarifier was returned to the aeration tank to maintain the desired culture concentration. The clarifier was contained within a 15 gallon aeration tank. Compressed air delivered through porous stone diffusers provided the aeration. The unit was maintained in a controlled temperature room set for 20°C, plus or minus one degree. Feed pumps were employed to continuously feed waste from agitated storage tanks to the treatment unit. Nutrient nitrogen in the form of aqueous ammonia was added to the simulated waste feed to the extent of 1 part nitrogen per 20 parts BOD. A schematic diagram of the pilot plant is presented in Figure 3.

Aerated Stabilization Basins

The flow sheet for aerated stabilization basins consisted of a completely mixed aeration basin without a secondary clarifier. A long detention time is employed to compensate for the limited concentration of culture that can be maintained in the aeration basin. Excess culture in a prototype installation will either settle in the aerated basin or be discharged with the effluent. Aeration was provided by compressed air delivered through porous stone diffusers. Six pilot plant units were employed, ranging in size from about 3.0 to 17 liters. The units provided detention times of from 1 to 4 days. Four of the units were fed simulated waste without nitrogen supplement and two units were fed simulated waste with nitrogen supplement to the extent of 1 part nitrogen per 20 parts BOD (added as aqueous ammonia). Temperature control was provided by maintaining the units in a controlled temperature laboratory at 20°C. A schematic diagram of the aerated stabilization basin process is presented in Figure 4.

Contact Stabilization

The flow sheet for contact stabilization consists of a completely mixed aerated contact tank followed by a secondary clarifier. The underflow from the secondary clarifier is recycled through an aerated stabilization tank enroute to the contact tank. Thus the process uses the "adsorptive" capacity of the activated sludge to remove pollutants in the contact stage and provides time for conversion of the absorbed material in a separate stabilization stage. The flow sheet normally permits a reduction in overall tank volume as compared with other activated sludge flow sheets.

The laboratory experiments investigated only the contact stage of the stabilization process since information was available from the extended aeration studies to evaluate the stabilization stage. The experiments consisted of the formulation of mixtures of known quantities of simulated waste and activated sludge. The mixtures were aerated and samples were withdrawn periodically for analysis of process performance in terms of removal of COD and suspended solids. The operation was performed as batch tests on a scale ranging from 0.5 to 2.0 liters. Temperature control was provided by keeping the units in a controlled temperature laboratory at 20°C. A schematic diagram of the contact stabilization process is presented in Figure 5.

Sludge Dewatering

A 15 gallon activated sludge pilot plant was employed as a waste sludge generator for use in sludge dewatering studies.

The pilot plant was maintained in a controlled 20°C environment and operated as an extended aeration waste treatment plant. The sludge loading was maintained at about 0.05 lb of BOD/lb of sludge. The concentration of suspended solids in the mixed liquor was relatively stationary at about 2,000 ppm. The aforementioned conditions effected a settleable culture with a typical sludge Volume Index of 145 ml/g. Samples of sludge were withdrawn from the pilot plant reactor as required for sludge dewatering studies.

Dissolved Air Flotation

Sludge dewatering studies using dissolved air flotation were conducted with a pressure bomb. The unit had a liquid capacity of 1 liter and was operated at a pressure of 70 psig. Variables evaluated were recycle, rise time, float volume and effluent suspended solids.

FIGURE 3

EXTENDED AERATION PROCESS

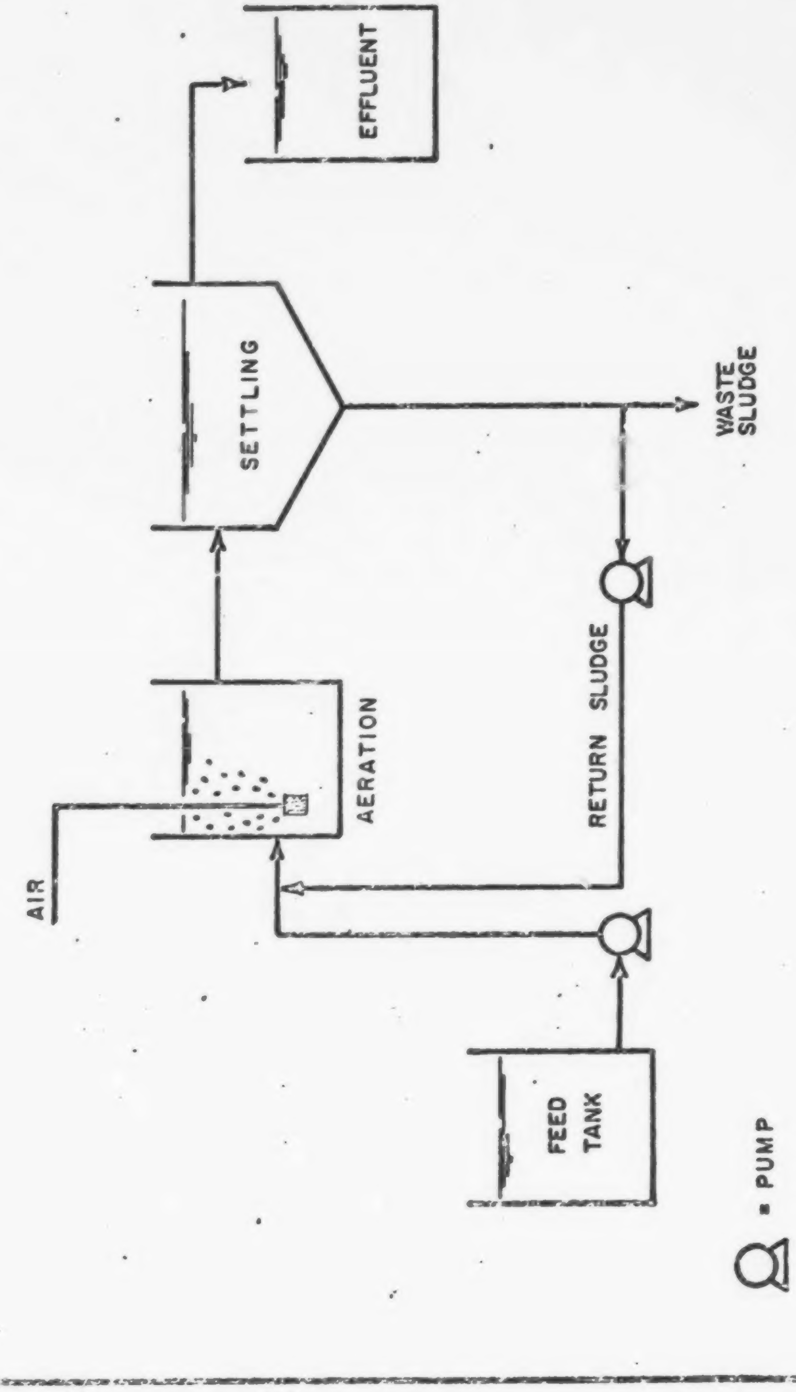


FIGURE 4

AERATED STABILIZATION PROCESS

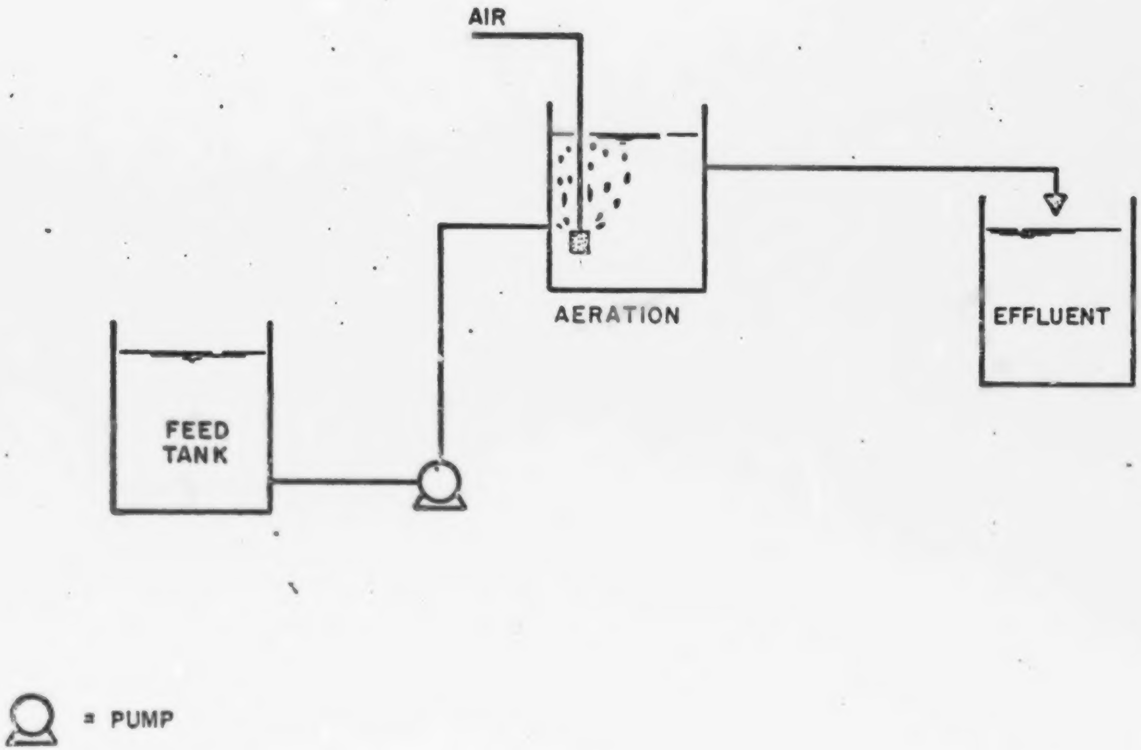
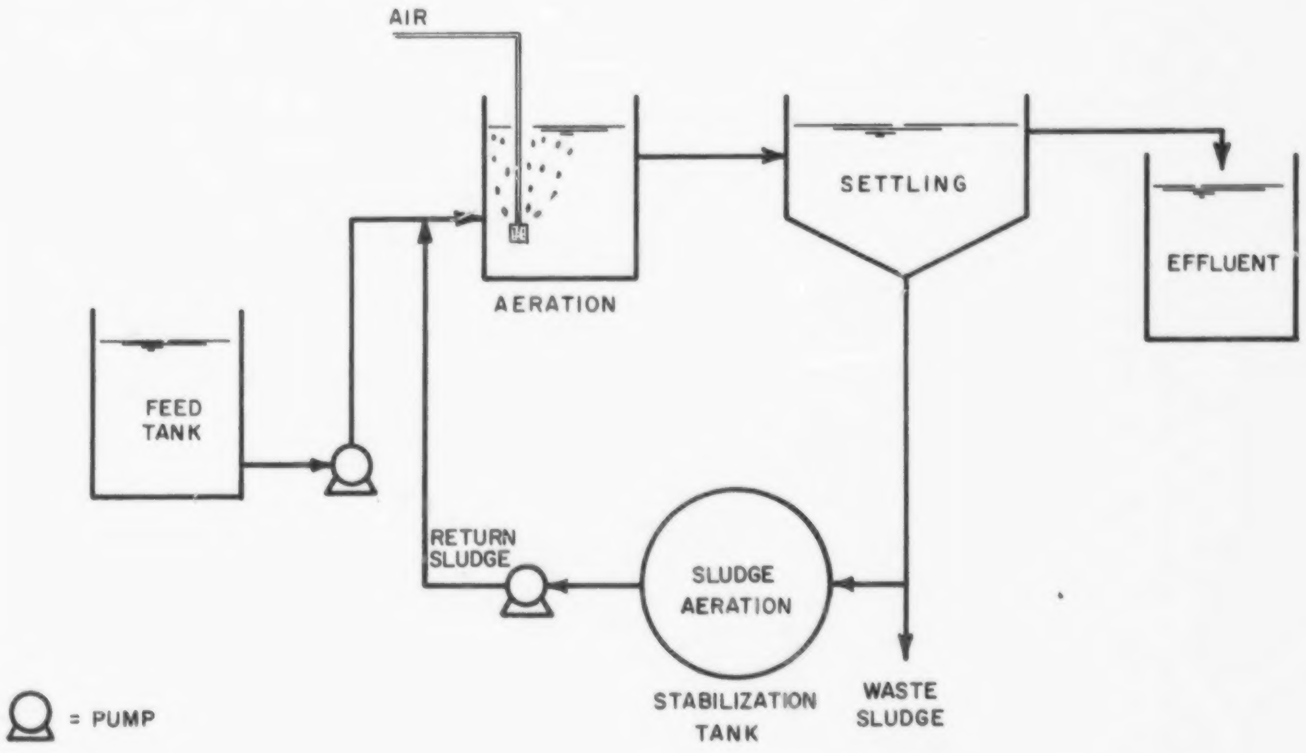


FIGURE 5

CONTACT STABILIZATION PROCESS



Bulked sludge was employed for a series of flotation experiments. The activated sludge was bulked by increasing the concentration and rate of feed to the unit. The bulking of the sludge caused the concentration of suspended solids in the mixed liquor to decrease from the unbulked level of about 2,000 ppm to a bulked level of 450 ppm. In all experiments the suspended solids concentration in the float was determined gravimetrically so as to eliminate interference due to entrapped air.

Centrifugation

Studies were made using a 10 ml laboratory spin test on sludge samples with and without polymer conditioning. The polymers employed for sludge conditioning were Dow A22, N17 and C31. Observations were made of the volume of the mud layer, the centrate turbidity and the dosage of conditioner.

Filtration

Samples of sludge, with and without chemical conditioning, were filtered on a Buchner funnel apparatus to determine the specific resistance to filtration. Conditioning agents were ferric chloride, ferric chloride and lime, and Dow C-31 polymer. The scale of the experimentation was 260 ml. Variables observed were time of filtration, volume of filtrate, vacuum level, sludge solids concentration before and after filtration, and dosage of conditioning agent.

Purifax Treatment

A sample of sludge was submitted to Purifax Incorporated, for treatment by the "Purifax Process" (chlorination) The dewaterability of the treated product was evaluated from Buchner funnel filtration tests and by sand bed characteristics.

Laboratory Scale Trickling Filters

Waste was fed to four laboratory test stand units to simulate trickling filter performance kinetics. The units, illustrated in figures 6 and 7, were rectanglular plane surfaces set at various inclines. Filter lengths were side channeled to provide a controlled surface area of slime. Units were constructed to provide flexibility in waste loading variation and system operation. Feed volumes were stored under refrigeration during feeding and collection. Slime surfaces were sufficiently large to enable the investigation of a wide range of BOD removal efficiencies.

Plane recirculation ratios and BOD and hydraulic loadings were scaled to approximate prototype conditions. Application of feed and recycle

FIGURE 6

TYPICAL LABORATORY SIMULATED
TRICKLING FILTER PLANE

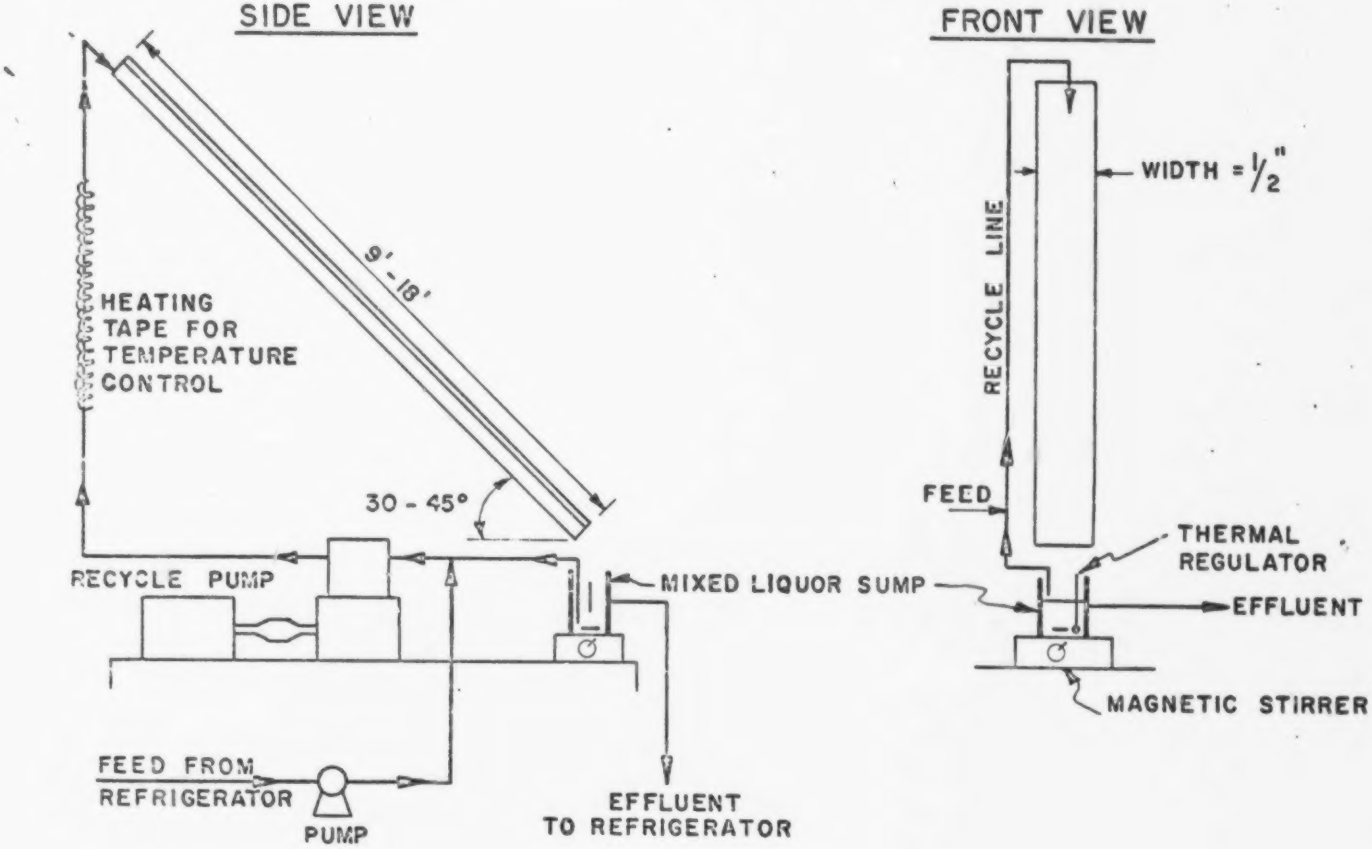
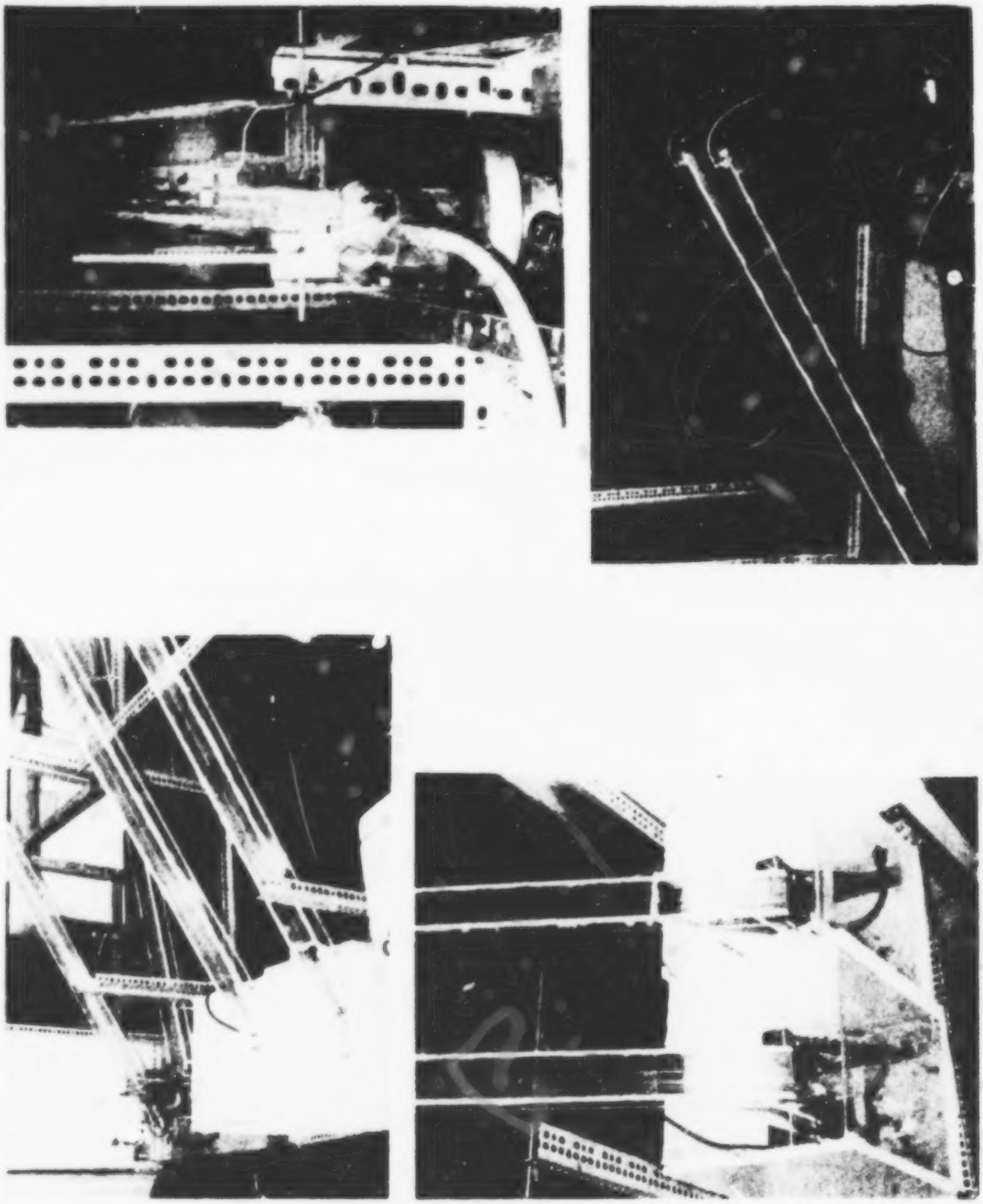


FIGURE 7



FILTER PLANE TEST STAND UNITS

was continuous with automatic temperature control. Operating characteristics are presented on Table 3. A period of 24 hours was allowed for development of steady state conditions between runs.

Table 3. Laboratory Trickling Filter Plane Operating Characteristics

Characteristics	Laboratory Trickling Filter
1. Number of Units Run	4
2. Total length (Feet)	9 and 18
3. Available Media (SF)	.375, .75 and
4. Volume of Feed Required per day (Liters)	3 - 22
5. Temperature	Automatic Control ± 2°C
6. Sampling Procedure	Manual Grab Samples
7. Duration of Runs	3 to 5 days
8. Operation Schedule	7 days/week
9. Method of Operation	
A. Feed	Continuous
B. Recycle	Continuous

Odor Control

The trickling filter planes were enclosed to deodorize the effluent air stream. A minimum air flow of 40 ft^3/gal was provided. Total air flow over the four trickling plans averaged 40 ft^3/hour. A Welsbach Model T-816 laboratory ozonator was chosen as the ozone source. Its rated capacity of 8 gms ozone/hr using air as the feed gas insured adequate capacity over and above the 10 ppm dosage recommended by the manufacturer for deodorizing sewage sludges. Control of ozonation was accomplished using a Welsbach Model H-81 ozone meter. A minimum reactor detention time of 5 minutes was provided before exhausting the deodorized air effluent outside the laboratory.

Solids-Liquid Separation

Several tests were performed on the laboratory trickling filter effluents to determine sedimentation characteristics. Effluent samples were settled for various detention times in a standard 500 ml polyethylene cylinder. Supernatent samples were withdrawn at the 150 ml level.

On-Site Pilot Plant

A pilot plant was used to treat whey effluent and whey effluent combined with settled sewage. The principal function of the on-site pilot plant was the generation of secondary sludge on a scale sufficient to enable the development of practical dewatering and disposal processes.

The pilot plant flow sheet consisted of a primary settling tank followed by trickling filtration and batch settling of filter effluent as shown on Figure 8.

The filter unit was supplied by the Koch Engineering Company and had a cross-sectional area of 7 sq ft with a media depth of 18 to 20 ft. The packing media was Koch Flexirings, a 3.5" plastic, webbed cylinder with a specific surface of 28 sq ft/cu ft.

The primary and final settling tanks were not evaluated for treatment performance on a continuous operating basis.

The majority of trickling filter samples were continuous composites for periods of typically 3 to 5 hours. Grab samples were taken for shorter filter runs.

The samples were analyzed at the QL&M laboratory on the day following their collection. Preservation was accomplished by acidification and refrigeration during transit and prior to analysis.

Sludge samples were obtained by collection of effluent into two 350 gallon settling tanks operated on a batch basis. After filling, the tanks were mixed and allowed to settle quiescently for one-hour. At the end of the settling period, the supernatent liquid was pumped to waste and the sludge was collected for shipment. Refrigerated samples of sludge were transported to the QL&M or other laboratories for analysis and evaluation.

Sludge Centrifugation

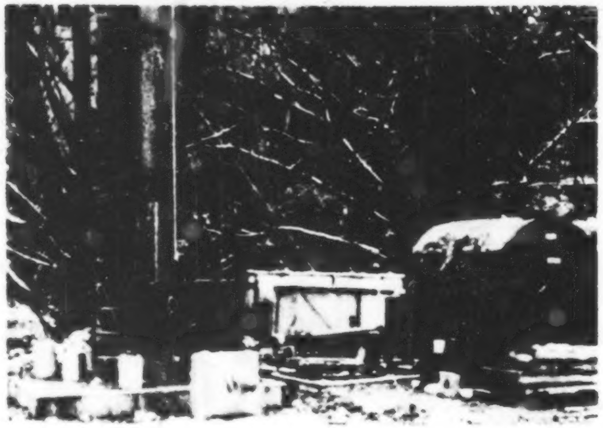
A centrifuge test of the trickling filter sludge was conducted by Sharples division of the Pennwalt Corporation.

A 100 gallon sample of a 0.74 percent sludge was used for the centrifuge test. Jar tests, for chemical aids, were conducted for a qualitative evaluation of coagulation. Nalco 610 appeared to be the most effective and was selected for evaluation during the centrifuge runs.

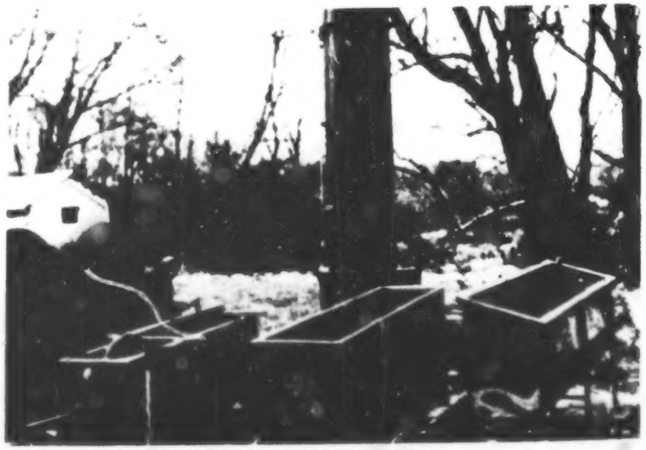
Two types of centrifuges were evaluated. The first was the Super-D-Canter P-600, which is a continuously fed, 6 inch, horizontal bowl centrifuge. The unit was evaluated at various feed rates without the addition of the chemical aid, and at a selected feed rate with various amounts of chemical aid.

The second centrifuge was a Fletcher Model 2PP-200, which is an automatic, cylically fed, vertical bowl centrifuge. This unit was evaluated at

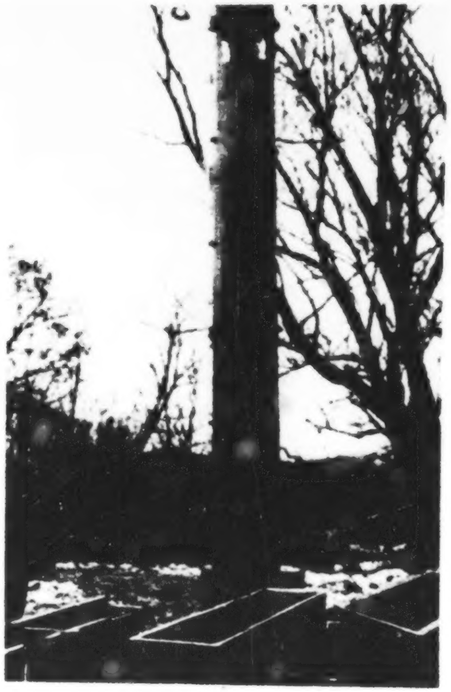
FIGURE 8



PACKED TOWER BASE & SEWAGE STORAGE TANKS



PRIMARY SETTLING TANK (LEFT)
TWO BATCH SECONDARY SETTLING TANKS (RIGHT)



PACKED TOWER, FULL LENGTH

TRICKLING FILTER PILOT PLANT

WALTON, NEW YORK

QUIRK, LAWLER & MATUSKY ENGINEERS

various feed rates without the addition of the chemical aid. The effect of chemical aid was estimated by assuming the same improvement as that which occurred with the Super-D-Canter. Samples of the centrate liquid and sludge cake were measured for suspended and total solids, respectively.

Figure 9 illustrates the equipment employed.

Vacuum Filtration

Sludge specific resistance measurements were used to select a chemical conditioner and its optimum dosage. The three conditioners evaluated were: ferric chloride, a Dow Chemical Company polymer Purifloc C-31, and lime addition in conjunction with ferric chloride.

Vacuum filter solids loading rates were determined by performing a series of filter leaf tests on a selected sludge sample.

PERFORMANCE OF FLUID BED BIOLOGICAL TREATMENT SYSTEMS

Extended Aeration BOD Removal

BOD removal performance was found to be excellent with capability of achieving removals in excess of 95 percent on a consistant basis. BOD removal rate kinetics were considerably higher than domestic sewage. Mixed liquor sludge settling characteristics were demonstrated to control process operation rather than BOD removal requirements.

Contact Stabilization BOD Removal

A good settling sludge from the extended aeration reactor was employed in the experiments, the results of which are summarized in Table 4. BOD removals in excess of 95 percent were demonstrated. The high effluent suspended solids concentrations indicated for the process discouraged additional investigation in a limited screening study. However, it is conceivable that with more intensive study an applicable process could be developed.

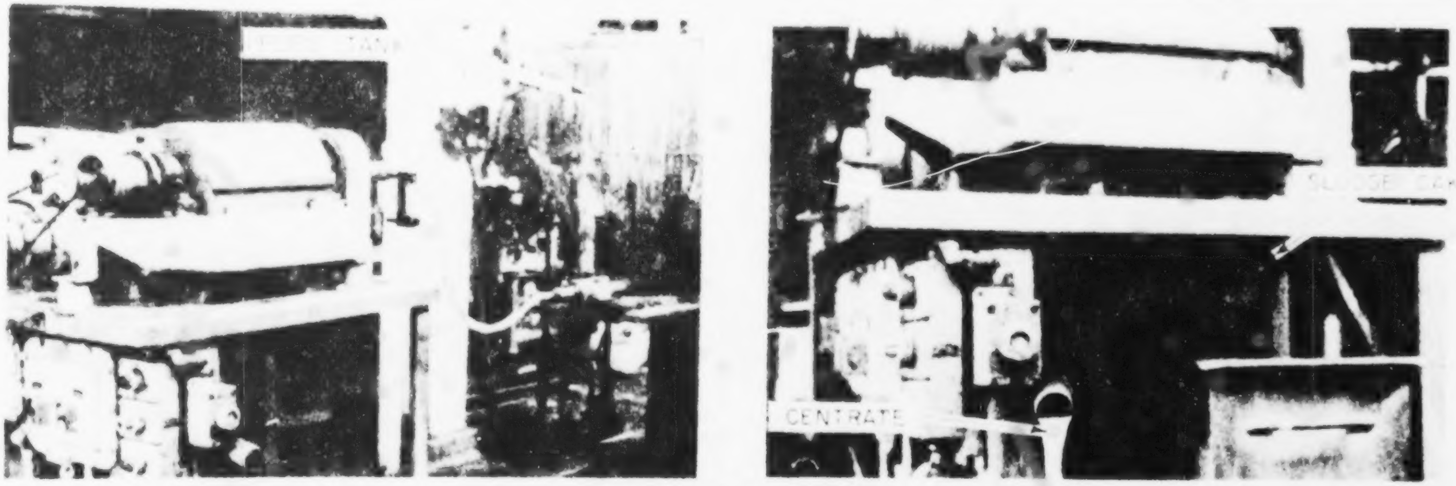
Biological Sludge Production

A material balance was constructed to evaluate the net sludge production resulting from BOD metabolism and endogenous respiration as follows:

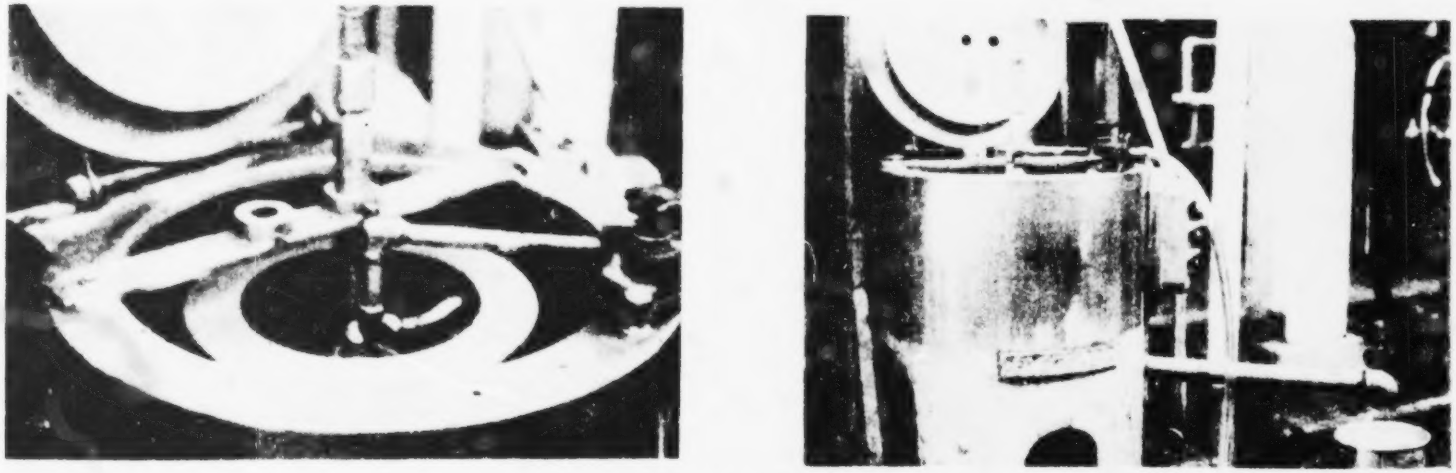
$$U_S = \frac{\Delta S}{S_A T_D} = Y_S U_L - U_E \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where: U_S = Velocity of net sludge production -
lb sludge produced/lb sludge under aeration/day

FIGURE 9



SUPER-D-CANTER



FLETCHER

QUIRK, LAWLER & MATUSKY ENGINEERS

U_L = Velocity of BOD removal - lb BOD removed/lb sludge under aeration/day

U_E = Velocity of endogenous metabolism of sludge - lb sludge metabolised/lb sludge under aeration/day.

Y_S = Sludge yield from BOD metabolism - lb sludge/lb BOD removed

S_A = Aeration solids concentration - ppm

T_D = Aeration detention time - days

ΔS = Net biological sludge production = ppm

The data obtained relative to sludge yield were split into categories of "with" and "without" nutrient supplement and analyzed statistically by a polyfit computer program. Results are presented in Table 5.

Table 4. Contact Stabilization Performance

Culture Conc.	Filtered Effluent @ Contact Time			Settled Effluent @ 60 min Contact Time	
S_A ppm	COD @ 15 min ppm	COD @ 30 min ppm	COD @ 60 min ppm	COD ppm	S_E* ppm
1650	684	640	589	974	482
3310	446	331	249	666	484
4950	68	92	25	278	217
6600	62	35	25	278	235

COD of Raw Waste = 1010 ppm

COD of Raw Filtrate = 982 ppm

Suspended Solids of Raw Waste = 98 ppm

*S_E = Effluent suspended solids concentration

Table 5. Biological Sludge Production
Average Parameters
Whey & Sewage

Parameter	With Nutrients	Without Nutrients
1. Y_S - lb Sludge/lb BOD Removed	0.400	0.700
2. U_E - lb Sludge/lb Sludge/day	0.055	0.065

The relationships obtained are employed for the estimation of the net biological sludge production under various operating conditions maintained in the aeration phase. The net production results from the particular balance between sludge production from BOD metabolism ($Y_S \cdot U_L$) and sludge destruction from endogenous respiration (U_E).

Oxygen Consumption

The total oxygen consumption attributable to BOD removal and biological culture requirements can be estimated from a material balance relationship as follows:

$$U_O = O_M U_L + U_E^{\prime} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Where: U_O = Velocity of net oxygen consumption - lb O_2/lb sludge under aeration/day

U_L = Velocity of BOD removal - lb/lb/day

$U_E^{\prime}$ = Velocity of endogenous oxygen consumption - lbO_2/lb sludge under aeration/day

O_M = Unit oxygen requirement for BOD metabolism

The relationship is employed to determine the total oxygen consumption under various operating conditions maintained in the aeration phase. The total oxygen demand results from the particular balance between metabolism requirements ($O_M \cdot U_L$) and endogenous respiration requirements ($U_E^{\prime}$).

The data collected for oxygen consumption were split into categories of "with" and "without" nutrient supplement prior to statistical processing by a polyfit computer program. Results are presented in Table 6.

Table 6. Oxygen Consumption
Average Parameters
Whey & Sewage Bio-Oxidation

Parameter	With Nutrients	Without Nutrients
1. O_M - lbO_2/lb BOD Removed	0.350	0.480
2. U'_E - lbO_2/lb sludge/day	0.075	0.065

Sludge Settleability

Factors that affect the settleability of the culture include waste characteristics, temperature, BOD removal velocity, nutrient supplementation and temperature. In the laboratory treatability studies observations were made of the effects of BOD removal velocity and nutrient supplementation on the settleability of the culture. Figure 10 gives the results obtained from determination of the settleability of the cultures prevailing in the seven reactors on a given day. The settleability is indicated by a Sludge Index which expresses the wet volume in milliliters, occupied by a gram of dry sludge solids after settling for a period of 30 minutes. Cultures were temperamental in respect to settling characteristics. The Sludge Index fluctuated in a random manner over a range of values of the BOD removal velocity. The only acceptable value of the Sludge Index was 108 ml/gram obtained with nutrient supplementation at a BOD removal velocity of 0.087/day. The other cultures were indicated to be poor settling and difficult to dewater. The results obtained throughout the studies indicated that when the BOD removal velocity reached a level of 0.2/day, the culture developed poor settling characteristics.

Some results obtained relative to the effects of BOD removal velocity and nutrient supplementation on effluent suspended solids concentration are given in Figure 11. The general trend of the results suggested that the lowest effluent suspended solids concentrations were obtained with nutrient supplementation and with low values of the BOD removal velocity.

Flotation

Laboratory flotation experiments were run with samples of activated sludge containing 2,000 to 3,200 ppm of suspended solids. Effluent suspended solids range from negligible concentrations to 25 ppm.

The rise time of the float is indicative of the velocity of separation of the solid phase. As such, it is the parameter governing the maximum hydraulic loading on the prototype unit. Empirical experience indicates

EFFECT OF BOD REMOVAL VELOCITY ON SLUDGE VOLUME INDEX

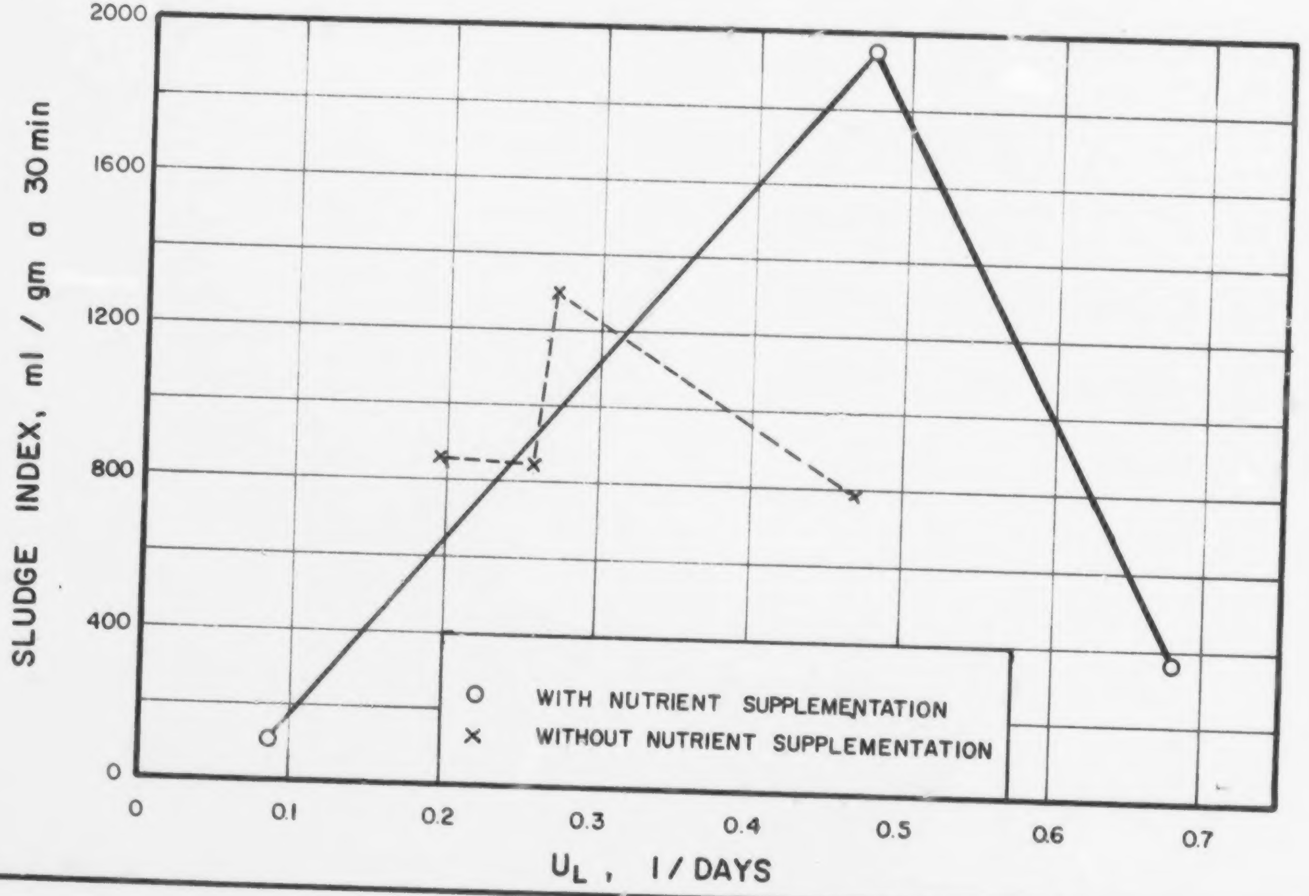
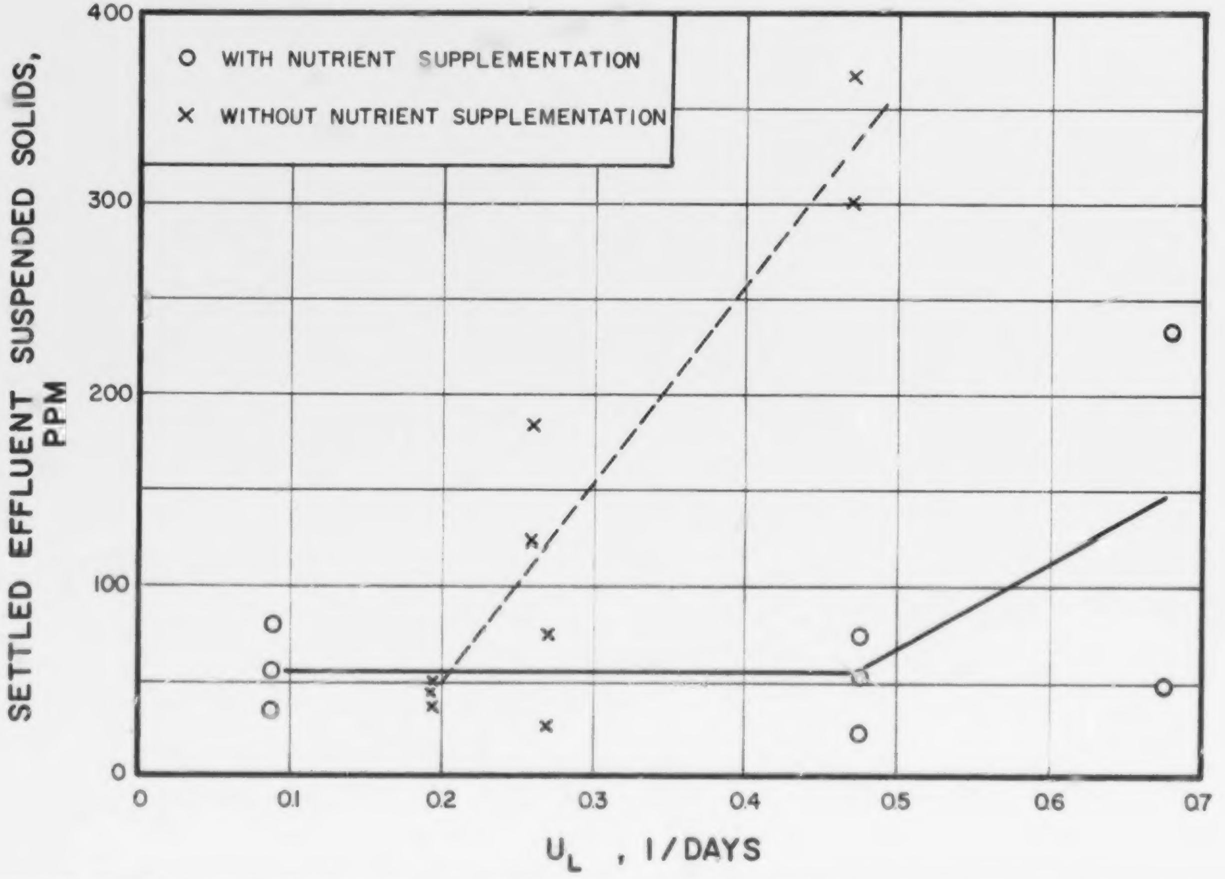


FIGURE 10

FIGURE 11

EFFECT OF BOD REMOVAL VELOCITY ON
SETTLED EFFLUENT SUSPENDED SOLIDS CONCENTRATION



that rise times of less than 40 seconds in the experimental unit are desirable in order to maintain performance stability in the prototype. Although long rise times may yield floats of improved concentration, there is a risk that release of attached bubbles may occur with subsequent redispersion of suspended matter. The effect of recycle ratio on the rise time for the two concentrations of activated sludge is illustrated in Figure 12. For design purposes, a recycle ratio of 2.0 would appear to be sound for the 2,000 ppm sludge. For design purposes, a gravimetric float solids value of 1.7 percent is selected as representative of prototype performance.

Centrifugation

Centrifuge spin tests were made on samples of activated sludge with a suspended solids concentration of 4,000 ppm. Poor results, indicated by cloudy centrate and indistinct separation were obtained on the sludge alone or when the sludge was conditioned with 100 ppm of Dow Polymers A-22 and N-17.

A clear centrate and a distinct solids separation was obtained with sludge conditioned with 50 ppm of Dow C-31. The mud layer amounted to 1.8 ml after 30 seconds. The indicated solids concentration of the mud layer was 2.2 percent. Centrifugation of a sludge sample conditioned with 9 ppm Dow C-31 produced a mud layer of 2.4 mls in 30 seconds and a slightly cloudy centrate. The indicated solids concentration of the mud layer was 1.67 percent.

Polymer dosage would be about 5 lb/ton of solids to yield a mud phase of 2.0 percent solids.

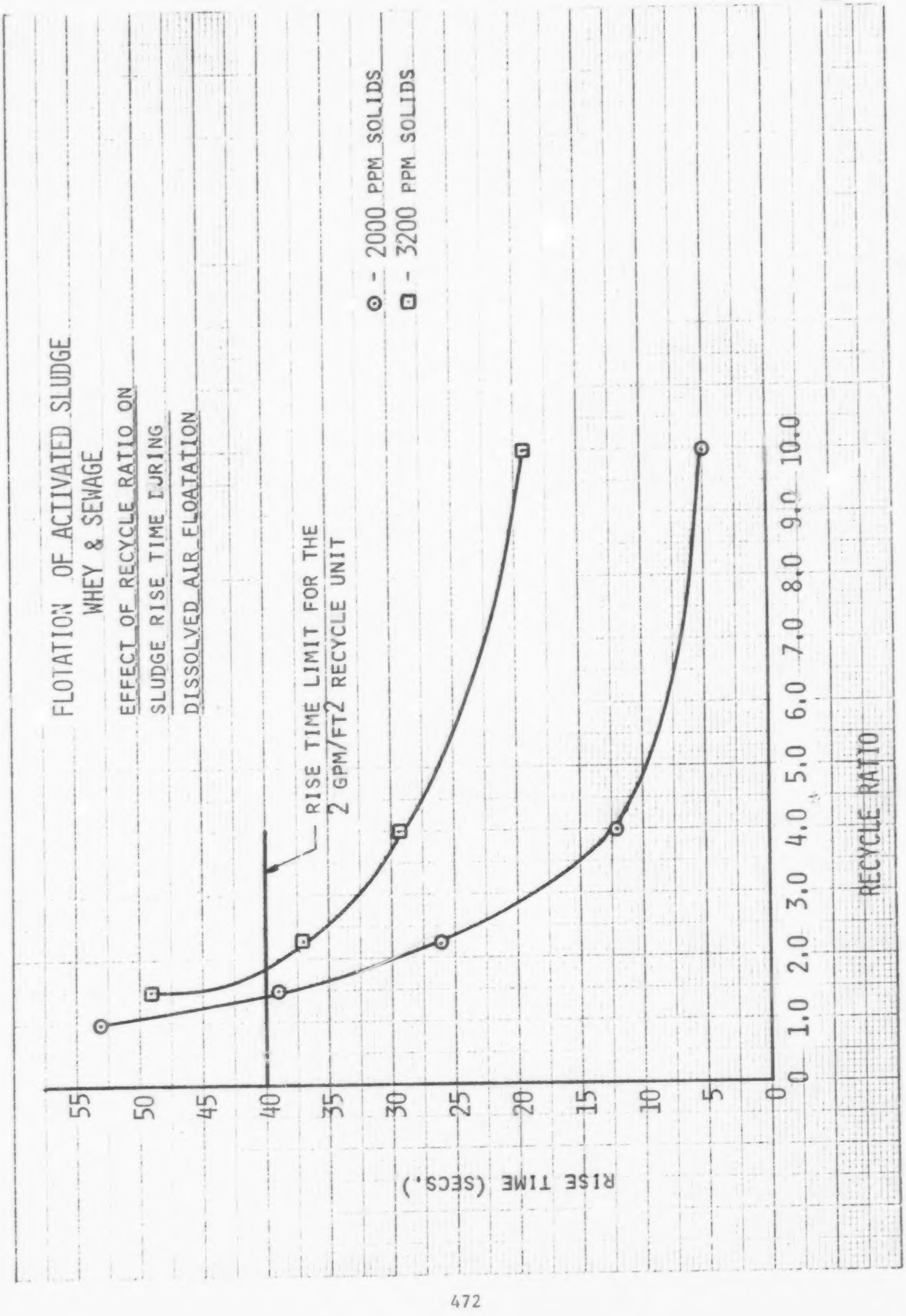
Vacuum Filtration

Laboratory experiments were made to determine the specific resistance to filtration of samples of activated sludge conditioned with ferric chloride, ferric chloride plus lime and a cationic polymer. The results indicated that ferric chloride alone was more effective than ferric chloride plus lime.

The practical dosage of ferric chloride for sludge conditioning was about 7 percent of the sludge dry solids. Solids in the dewatered product was only 11 percent. The conditioning procedure effected a 3.3 fold increase in filterability.

Results were obtained for sludge conditioned with cationic polymer (Dow C-31). At a practical conditioning dosage of about 0.5 percent of the sludge dry solids, the polymer effected a 2.3 fold increase in filterability. The solids in the dewatered product was 10 percent.

FIGURE 12


FLOTATION OF ACTIVATED SLUDGE
WHEY & SEWAGE
EFFECT OF RECYCLE RATIO ON
SLUDGE RISE TIME DURING
DISSOLVED AIR FLOATATION
RISE TIME LIMIT FOR THE
2 GPM/FT2 RECYCLE UNIT
⊙ - 2000 PPM SOLIDS
⊡ - 3200 PPM SOLIDS
RISE TIME (SECS.)
55
50
45
40
35
30
25
20
15
10
5
0
0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
RECYCLE RATIO

Based on the experimental results, it is calculated that the vacuum filter yields for sludge conditioned with ferric chloride and with C-31 Polymer would be 1.5 and 1.25 pounds dry solids/sq ft/hr respectively at solids concentrations of 10 percent.

Purifax Process

A sample of activated sludge containing 4,500 ppm suspended solids was transmitted to the Purifax Corporation for processing. The chlorine demand of the sample was determined to be 78 ppm. The sample was "Purifaxed" with approximately 98 ppm of chlorine with the result that within a few minutes the solids floated and were removable by skimming. The pH after processing was less than 3.0. The residual solids were rapidly dewaterable on an underdrained sand bed or on a Buchner funnel filter. The dewatered cake could be lifted from the sand bed after 20 minutes. No decomposition of the Purifaxed sludge liquor or the dewatered cake was evident on standing for a month. Neutralization of the Purifaxed sludge liquor with lime prior to filtration adversely affected dewatering properties.

After degassification, the Purifaxed sludge settled readily to a sludge concentration of 2.0 percent solids in 30 minutes. Untreated sludge would settle typically to a concentration of about 0.59 percent solids in 30 minutes. The improved settling characteristics represented a 70 percent reduction in the volume of sludge to be handled.

The specific resistance to filtration of the Purifaxed sludge was determined. By calculation, it was estimated that the material would dewater on a vacuum filter to 9 percent solids at a rate of 0.6 pounds dry solids/ sq ft/hr.

TRICKLING FILTRATION PERFORMANCE

Laboratory Simulation

The classic trickling filter comprises a bed of stone media over which attached biological slime growths develop. Removal of BOD is obtained by aerobic processes at the slime surface and by anaerobic processes within the slime interior. Packed tower modifications to the trickling filter introduced plastic geometric packing media to obtain increased surface area and porosity. Current practice employs a lattice structure similar to an egg carton insert. BOD removal performance is related to process parameters using an analytical model descriptive of the biological relation observed and the hydraulics of the reactors.

BOD changes (at constant temperature) in flow over an inclined plane or through a full scale packed tower have been shown to follow a first order reaction and to be related as follows:(39)

Inclined plane: $$\frac{L_e}{L_o} = e^{-k'H/U} \tag{3}$$

Packed Tower (Surfpac or equal):

$$\frac{L_e}{L_o} = e^{-K_T H/U} \tag{4}$$

Where: H = Tower or plane height in feet

U = Liquid application rate expressed as: gpm/LF of plane width for laboratory units and gpm/SF of tower area for full-scale units.

k' = Specific BOD removal rate constant for effluent treated obtained from laboratory analysis.

K_T = BOD removal rate constant for particular packing media used in full scale tower.

The value of k' is specific for the effluent treated. The value of K_T varies with the type of full scale packing media used and is computed using the value of k' and the characteristics of the media.

A graphical solution to equation (3) is obtained by taking logarithms. Temperature effects are adjusted to 20°C by applying the Arrhenius correction ($\theta^{\Delta T}$) to the height variable.

A plot of data on semi-log paper will provide a linear correlation with slope equal to ($k'/2.3$) and an intercept of 1.0 at $H\theta^{\Delta t}/U' = 0$ as shown on Figure 13. The graphical technique is employed in the analysis of test data.

Figure 14 is a presentation of biological filter plane results. The linearity of the plot over the wide range of operating conditions, verifies the applicability of the kinetic formulation. For the conditions represented by the plot, the BOD removal rate coefficient, k'_{20}, was computed as 1.6×10^{-3} gpm/ft^2. The literature was reviewed for whey data to which the correlation could be applied. The data of Schultze(31) were analyzed for whey application over a vertical surface comprised of a screen mesh. The correlation is shown on Figure 14 and supports a (k') value of 1.6×10^{-3} gpm/ft^2.

Laboratory reaction rates are scaled to full scale conditions for a media similar to Surfpac using the following relationship(39):

$$(K_T) = k' \cdot A_v \cdot f_t \cdot C_w \tag{5}$$

FIGURE 13

GRAPHICAL SOLUTION OF SLIMED PLANE

BOD REMOVAL PERFORMANCE EQUATION

FIRST ORDER REACTION

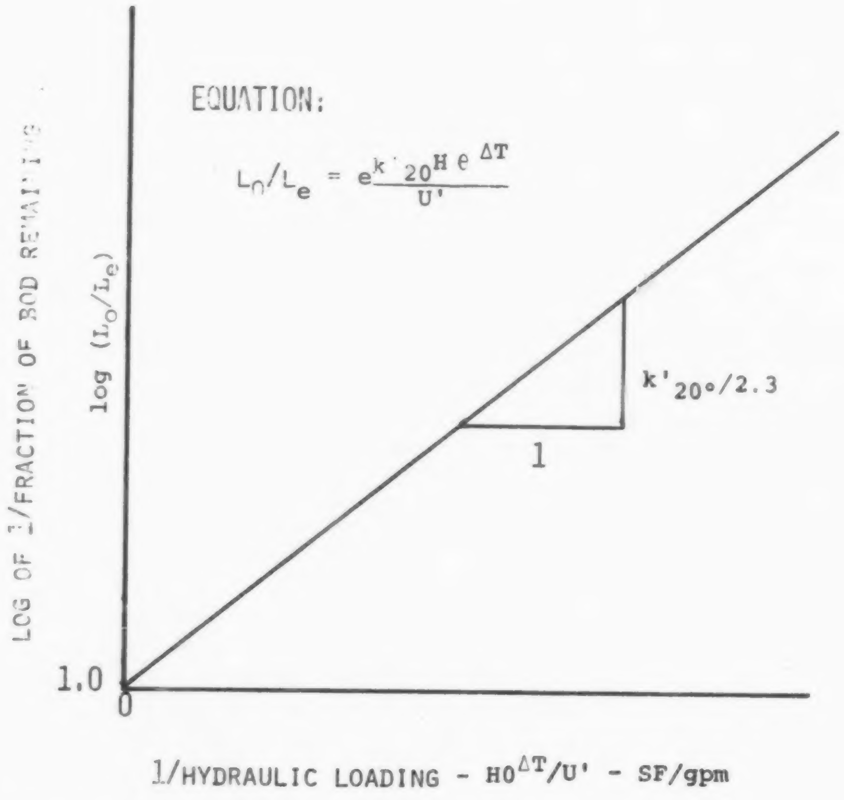
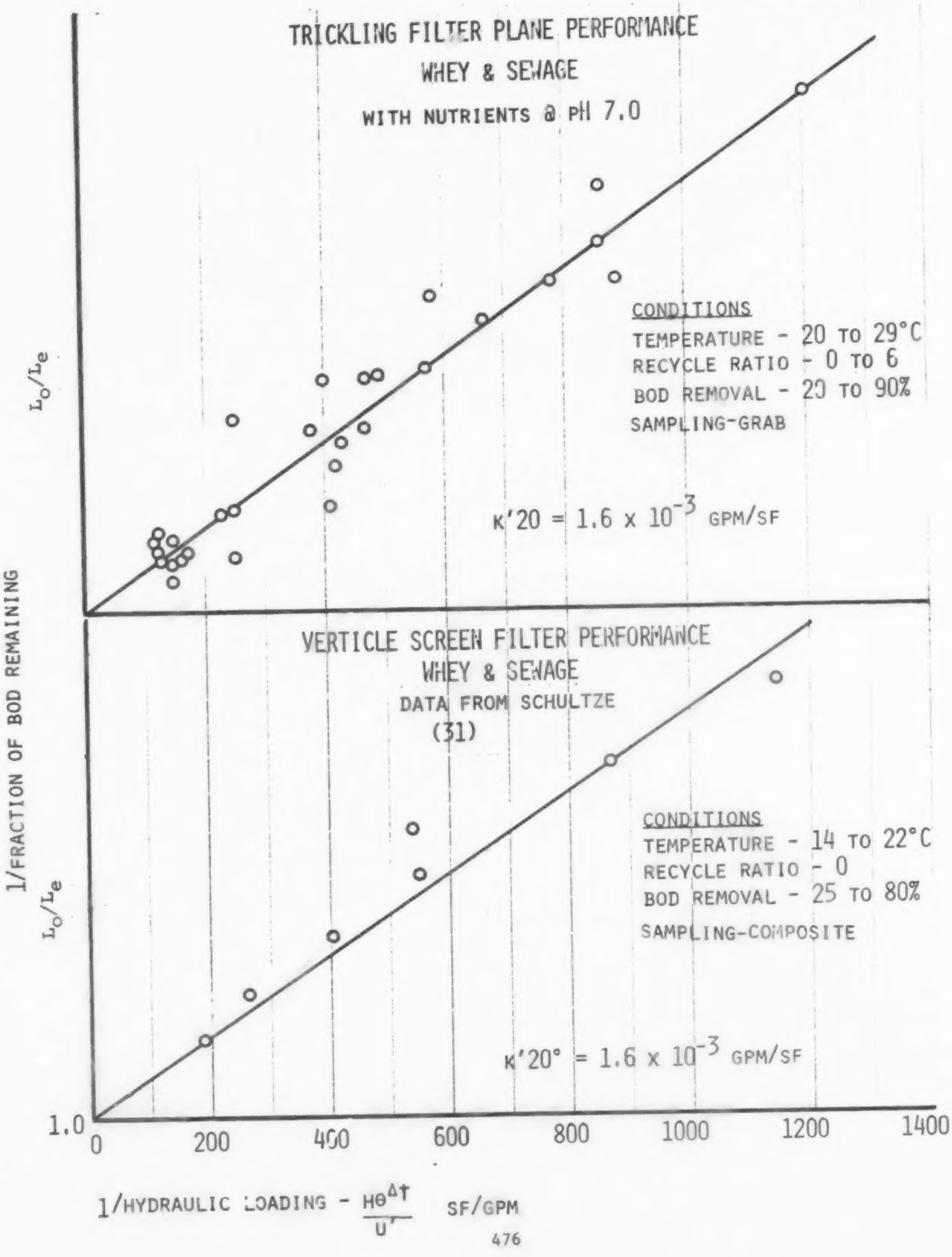


FIGURE 14


TRICKLING FILTER PLANE PERFORMANCE
WHEY & SEWAGE
WITH NUTRIENTS @ pH 7.0
CONDITIONS
TEMPERATURE - 20 TO 29°C
RECYCLE RATIO - 0 TO 6
BOD REMOVAL - 20 TO 90%
SAMPLING-GRAB
K'20 = 1.6 x 10-3 GPM/SF
L_o/L_e
VERTICLE SCREEN FILTER PERFORMANCE
WHEY & SEWAGE
DATA FROM SCHULTZE
(31)
CONDITIONS
TEMPERATURE - 14 TO 22°C
RECYCLE RATIO - 0
BOD REMOVAL - 25 TO 80%
SAMPLING-COMPOSITE
K'20° = 1.6 x 10-3 GPM/SF
L_o/L_e
1/FRACTION OF BOD REMAINING
1.0
0
200
400
600
800
1000
1200
1400
1/HYDRAULIC LOADING - $\frac{H\theta^{\Delta t}}{U^r}$ SF/GPM

Where: $k'20$ = BOD removal rate constant
1.6×10^{-4} gpm/SF for whey sewage

A_v = Specific surface of media
27 SF/CF for Surfpac

f_t = Factor for slime area reduction due to slime thickeners
0.8 for whey and sewage

C_w = Factor for efficiency of wetting of full scale media 0.90 for Surfpac

and $K_T = 1.6 \times 10^{-4} \times 27 \times 0.8 \times 0.9$

$= 0.03$ gpm/CF

A comparison between the treatability of whey and other industrial effluents using full-scale packed towers and a media similar to Surfpac demonstrates the treatability of whey effluent as follows:

Trickling Filtration of Whey
Comparison of Full Scale BOD Removal Rate Constants

Effluent	K_T- gpm/CF
1. Ragmill	.083
2. Slaughter House	.044
3. Integrated Kraft Mill (Average)	.031
4. Whey	.030
5. Boxboard Mill	.027
6. Canning	.021

Effect of pH

The level of pH influences enzyme activity and culture characteristics in biological systems. The results of a limited number of data collection runs at different levels of influent pH indicated a trend towards improved performance in the pH 7 or below. It is noted that similar trends were obtained by Wasserman(1) and Adamse(4) with other biological systems using whey as substrate. Data indicate an increase in rate constant from 1.1 @ pH = 9.8 to 2.8 @ pH = 4.5

Effect of Temperature

Temperature effects are introduced by adjustment of the value of the BOD removal coefficient, k' in the following manner:

$$k'_t = k'_{20}\,\theta^{(t-20)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

where: k'_t = BOD removal rate coefficient at T°C

k'_{20} = BOD removal rate coefficient at 20°C

θ = Constant

t = Waste temperature, C°

A series of experiments made over the temperature range from 19 to 30°C is shown on Figures 15 and 16. The value of k' increased with temperature from 1.6×10^{-3} gpm/ft^2 at 20°C to 2.2×10^{-3} gpm/ft^2 at 29°C. The average value of θ was computed as 1.032, as shown on Figure 17, and was in agreement with the value assumed in current practice.

Effect of Nutrients

A series of experiments were made to determine the effect of nutrient supplementation upon BOD removal performance. The nutrients selected for investigation were combinations of ferrous iron and ammonia. Data analysis indicated that the addition of 1.5 ppm of ferrous iron had no effect on BOD removal, whereas the addition of 37.5 ppm of ammonia-nitrogen effected a 40 percent increase in the rate coefficient for BOD removal. Comparisons of trickling filter plane performance with and without nutrient addition are shown on Figure 18.

Odor Generation

During the experimental work, odor was detected only at the higher BOD loadings, above .036 lb BOD/day-ft^2 of slime area. Application of ozone at an approximate dosage of 10 ppm effectively deodorized the effluent air stream. No evidence of odor was detected either in the laboratory or at the air effluent exhaust.

Pilot Plant Performance

Erratic performance was attributed in part to plugging of the media due to the lack of free-fall and to the extensive slime growth effected at high loadings. Poor performance, black sludge and poor draft in smoke tests were evidence that the pilot plant was occasionally effected by anaerobic conditions. Substantial scatter of performance was evident but a trend for better than 50 percent removal was exhibited for BOD loadings of less than 150 ptcfd.

Sludge Production

Biological sludge production data was collected for a period of four days. The average biological solids production approximated 1.0 lb of dry solids/lb of BOD removed. During the period of observation the BOD removal of the trickling filter averaged 75 percent. Generally, low yields are associated with high degrees of BOD removal (85-95 percent).

FIGURE 15

TRICKLING FILTER PLANE PERFORMANCE
WHEY & SEWAGE, WITH NUTRIENTS
EFFECT OF TEMPERATURE

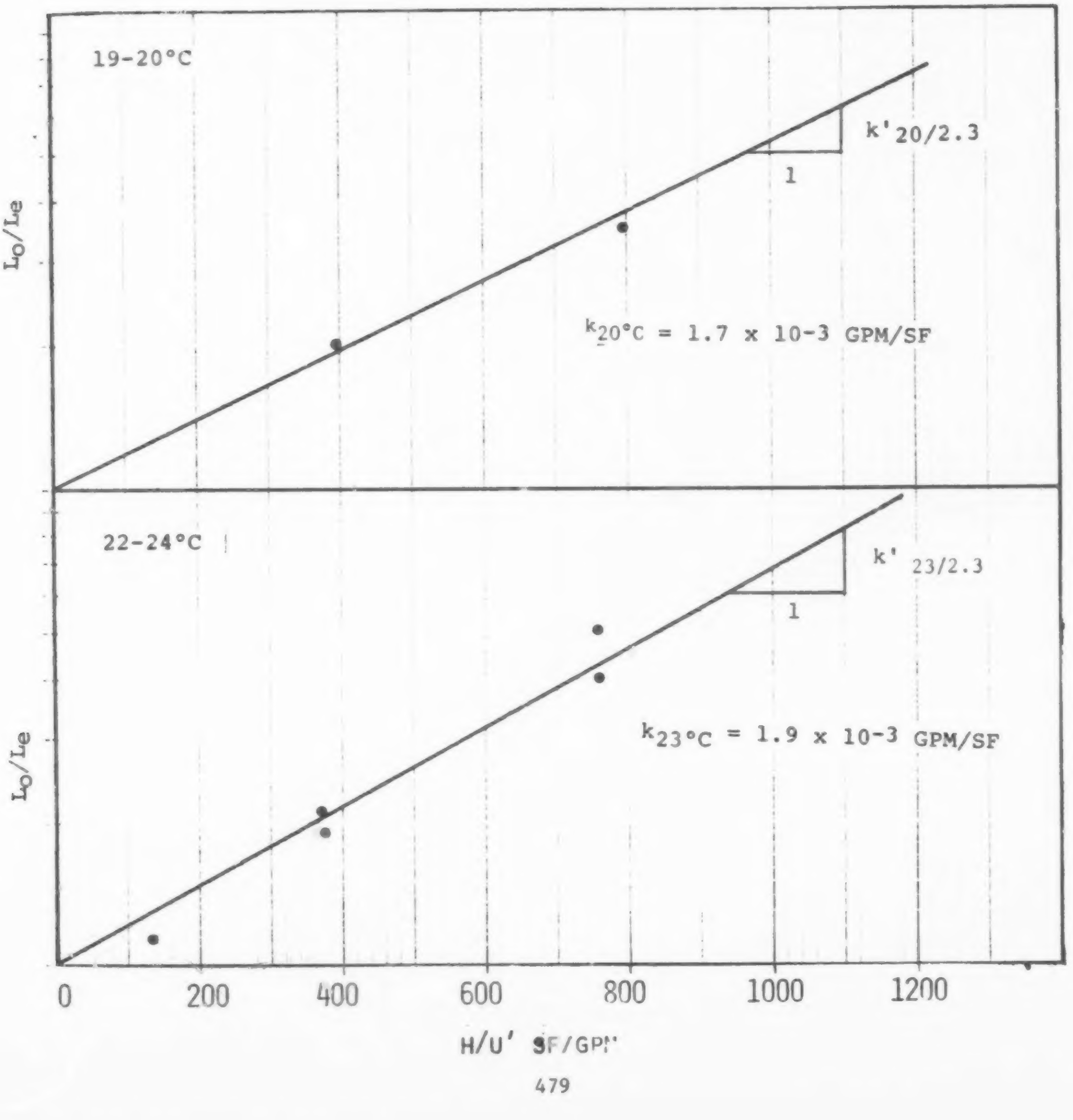


FIGURE 16

TRICKLING FILTER PLANE PERFORMANCE
WHEY & SEWAGE, WITH NUTRIENTS
EFFECT OF TEMPERATURE

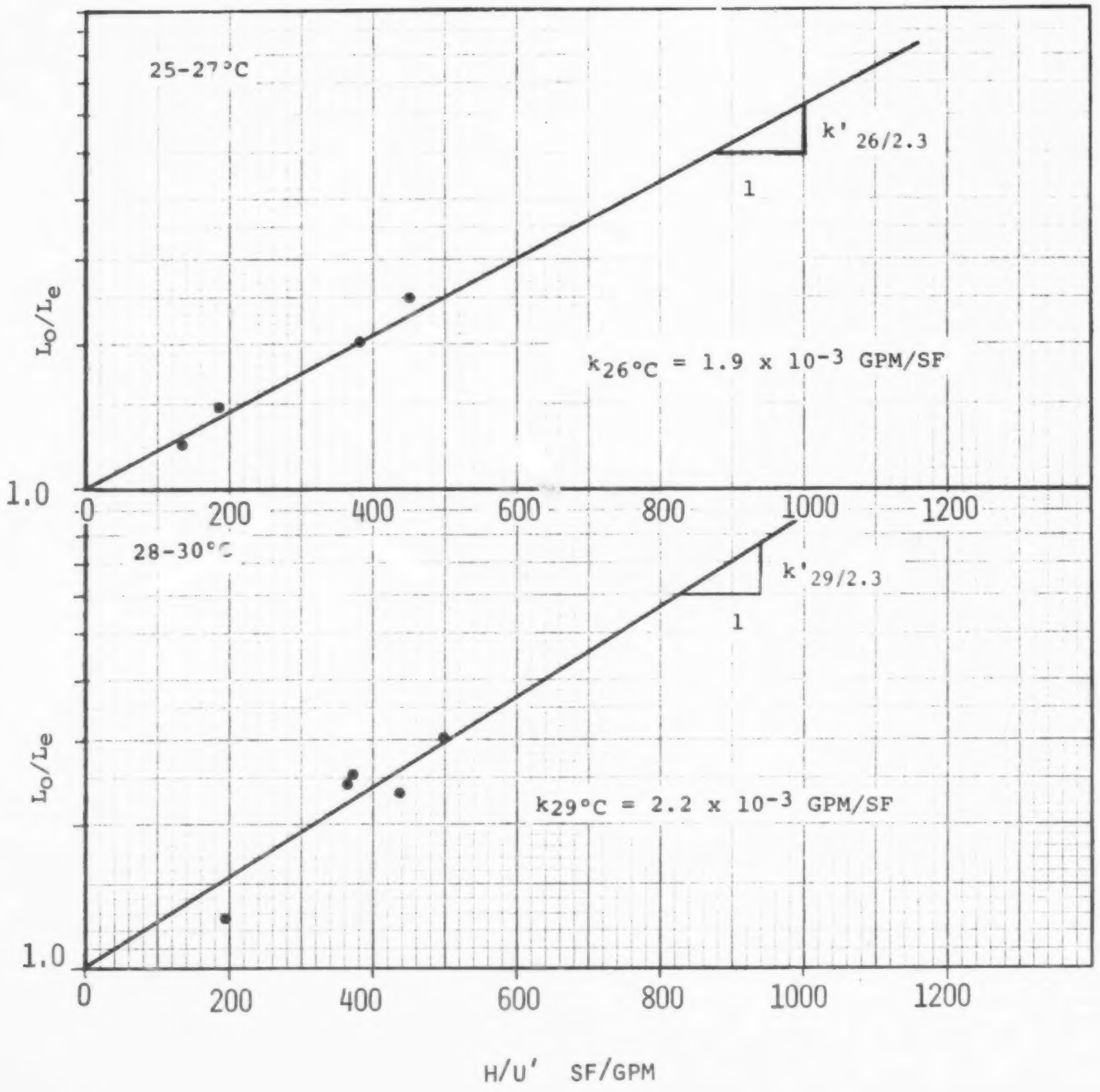


FIGURE 17

TRICKLING FILTER PLANE PERFORMANCE
WHEY & SEWAGE WITH NUTRIENTS
EFFECT OF TEMPERATURE ON BOD RATE CONSTANT

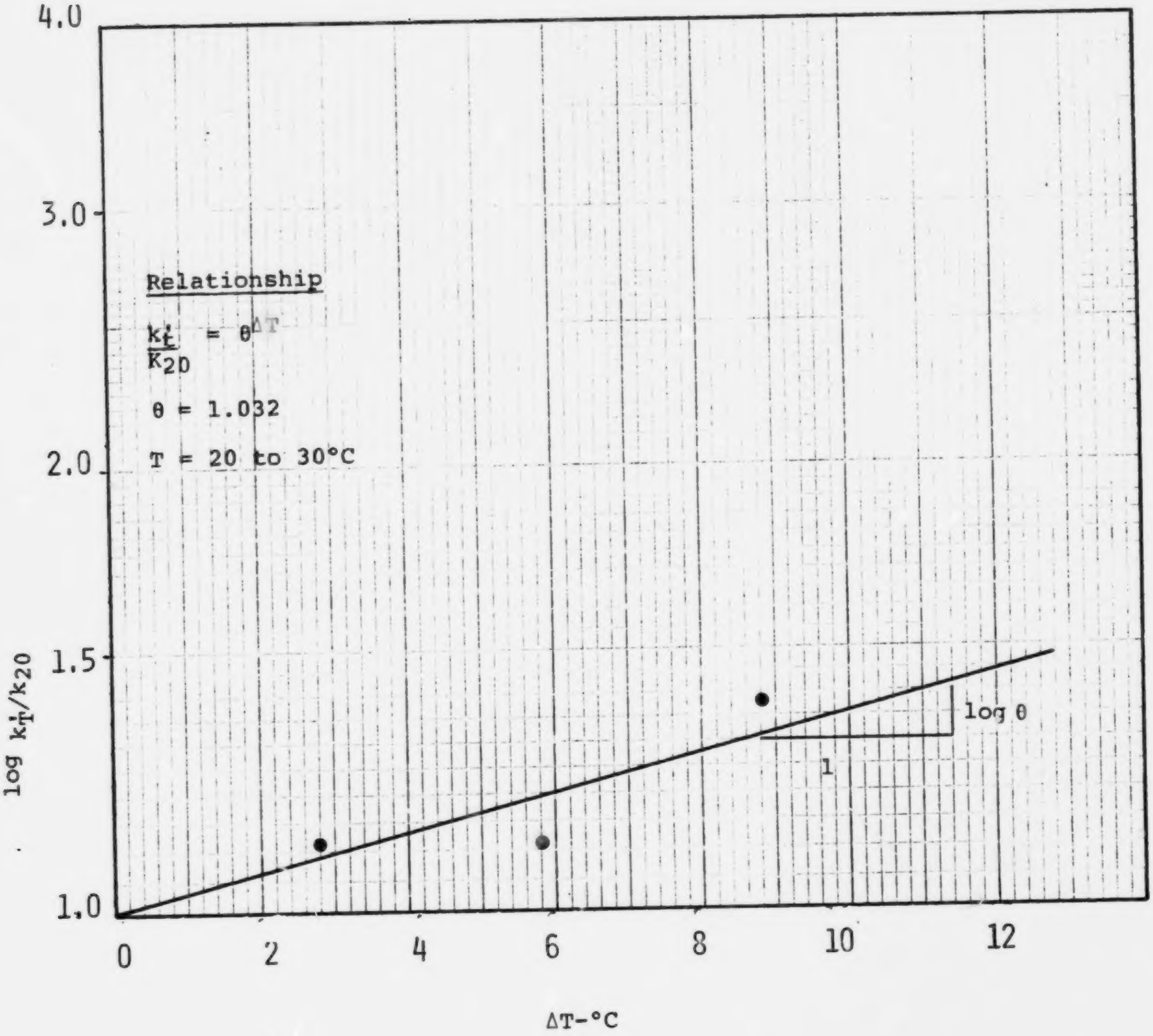
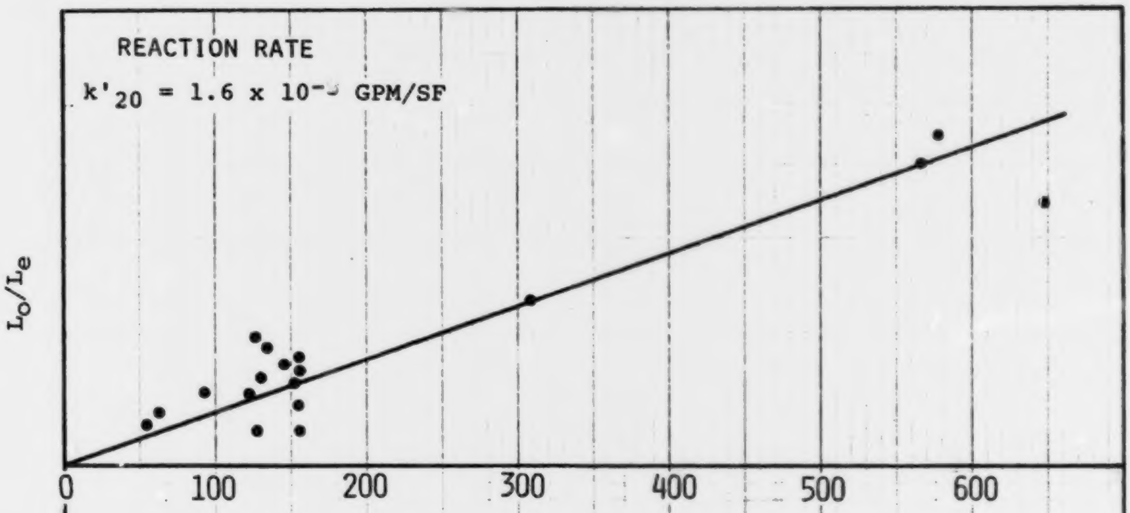
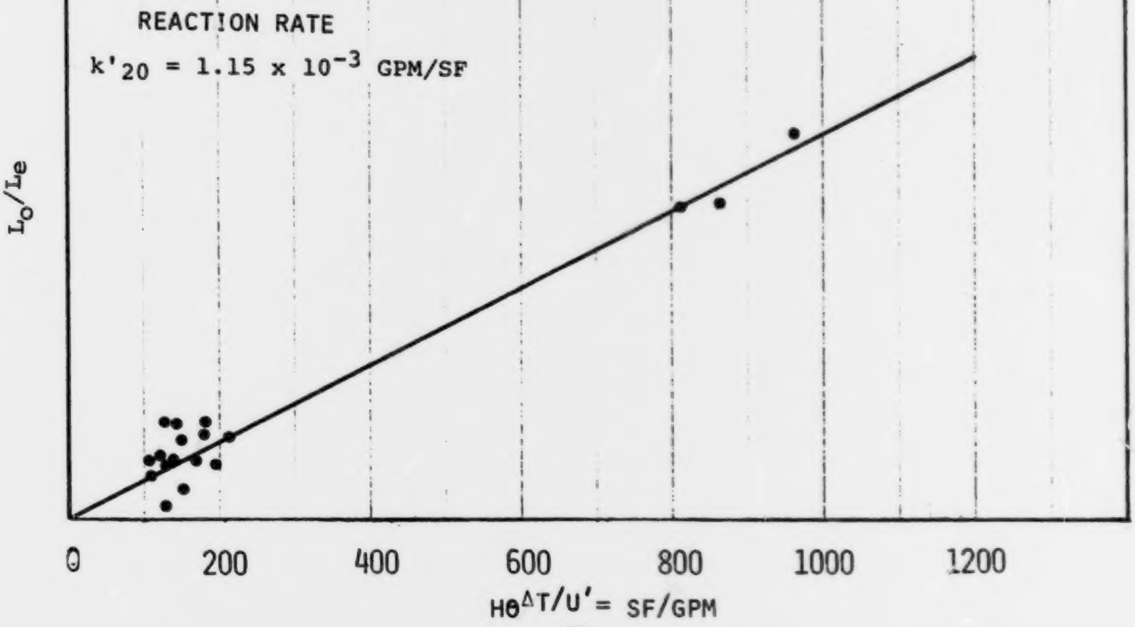


FIGURE 18

TRICKLING FILTER PLANE PERFORMANCE
WHEY & SEWAGE
DISSOLVED BOD REMOVAL
OPERATION WITH NUTRIENTS @ PH = 7.0



TRICKLING FILTER PLANE PERFORMANCE
WHEY & SEWAGE
OPERATION WITHOUT NUTRIENTS @ PH 7.0



Lower degrees of removal normally generate higher sludge yields. The field studies were not extensive enough for the development of a sludge production model. A value of 0.7 lb of SS/lb of BOD removed is recommended for biological sludge production for the blend of whey waste and sewage. This value equals the biological yield coefficient for activated sludge treatment.

Solids Liquid Separation & Compaction

Figure 19 illustrates the supernatant suspended solids after varying detention times for a given trickling filter plane operating condition with differing effluent suspended solids.

Projecting the data, a supernatant suspended solids concentration of between 75 to 100 mg/1 would be expected from gravity sedimentation.

Measurement of pilot plant filter effluent clarification was made, routinely, by pumping the trickling filter effluent into the holding tanks. When full, the tank was sequentially mixed, sampled, allowed to settle for 30 minutes, and resampled near the surface. The suspended solids removal averaged 80 percent. This should be considered a limiting value, i.e., attainable at low overflow rates, unless chemicals are used to aid settling.

Suspended solids present in the untreated whey and in the trickling filter effluent have been shown to exhibit a BOD equivalent to 60 percent of their weight. The achievement of high overall degrees of treatment will require that suspended solids in the final effluent be limited to minimum values.

Settling characteristics of trickling filter solids are such as to require coagulant addition in order to insure minimum suspended BOD in the treated effluent.

Clarifier underflow is expected to be approximately 1 percent solids and to thicken to 2 percent at a sludge loading of 6.0 lb/SF/Day.

Centrifuge Results

Table 7 presents results for all the centrifuge runs. The addition of 9.3 lb of chemical/ton of dry solids at a feed rate of about 19 lb/min raised the percent recovery of the Super-D-Canter to the level of the Fletcher model. The cake solids concentration of the Super-D-Canter and the Fletcher were respectively 6 percent and 9 percent.

Both models appear to give reasonable feed rates for acceptable recoveries of 80 to 85 percent. However, both models' cake solids concentrations are well below the desired values.

FIGURE 19

TRICKLING FILTER PLANE EFFLUENT
FINAL SEDIMENTATION TESTS

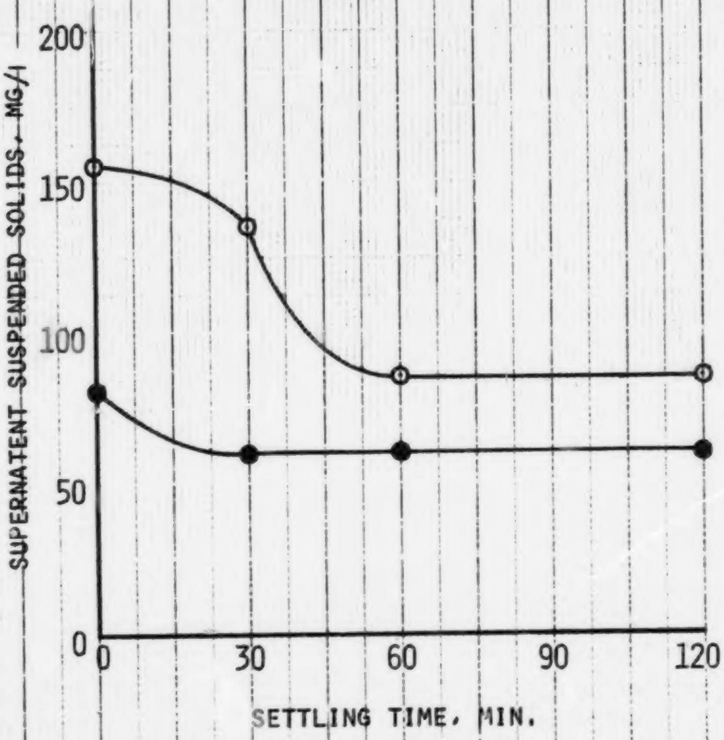


TABLE 7

TRICKLING FILTRATION TREATMENT

WHEY & SEWAGE

CENTRIFUGATION OF WASTE SLUDGE

Slurry Feed Rate lbs/min.	Chemical Aid Feed Rate Lbs/Ton of Dry Solids	Super-D-Canter P-600		Fletcher 2PP-200	
		% Recovery	Cake Solids, %	% Recovery	Cake Solids, %
2.1	-	-	-	99.2	Average of 9%
6.5	-	-	-	99.4	
9.5	-	-	-	93.7	
23.5	-	-	-	77.2	
6.8	-	98.9	5.5	-	
9.9	-	98.7	6.3	-	
18.9	-	59.0	-	-	
23.7	-	59.8	5.7	-	
18.3	9.3	81.7	5.9	-	
19.2	19.6	82.1	-	-	
19.3	33.0	86.7	6.5	-	

Vacuum Filtration

Ferric chloride and Purifloc C-31 were compared using dosages of comparable cost. The results favored the use of ferric chloride rather than the polymer. Various dosages of lime in conjunction with a constant dosage of ferric chloride were evaluated. Specific resistance was found to increase as lime was added to the samples. For this reason, lime was eliminated from consideration and ferric chloride was selected as the conditioner for further tests and final design.

The determination of the optimum dosage of ferric chloride was made by measuring specific resistance versus dosage on three representative samples. Seven pounds of ferric chloride/ 100 lb of suspended solids was selected as the optimum dosage.

Figure 20 presents a summary of test conditions and results.

Solids dewatering by vacuum filtration could be achieved at an indicated loading of 1.2 lb/SF/hr using 7 percent $FeCl_3$ to produce a cake of 20-25 percent solids.

Odor generation from the acidified conditioned sludge will require that special ventilation facilities be incorporated in the design of sludge filtration facilities.

TRICKLING FILTRATION & ACTIVATED SLUDGE COMPARISONS

Process comparisons between packed tower trickling filtration and activated sludge are summarized as follows:

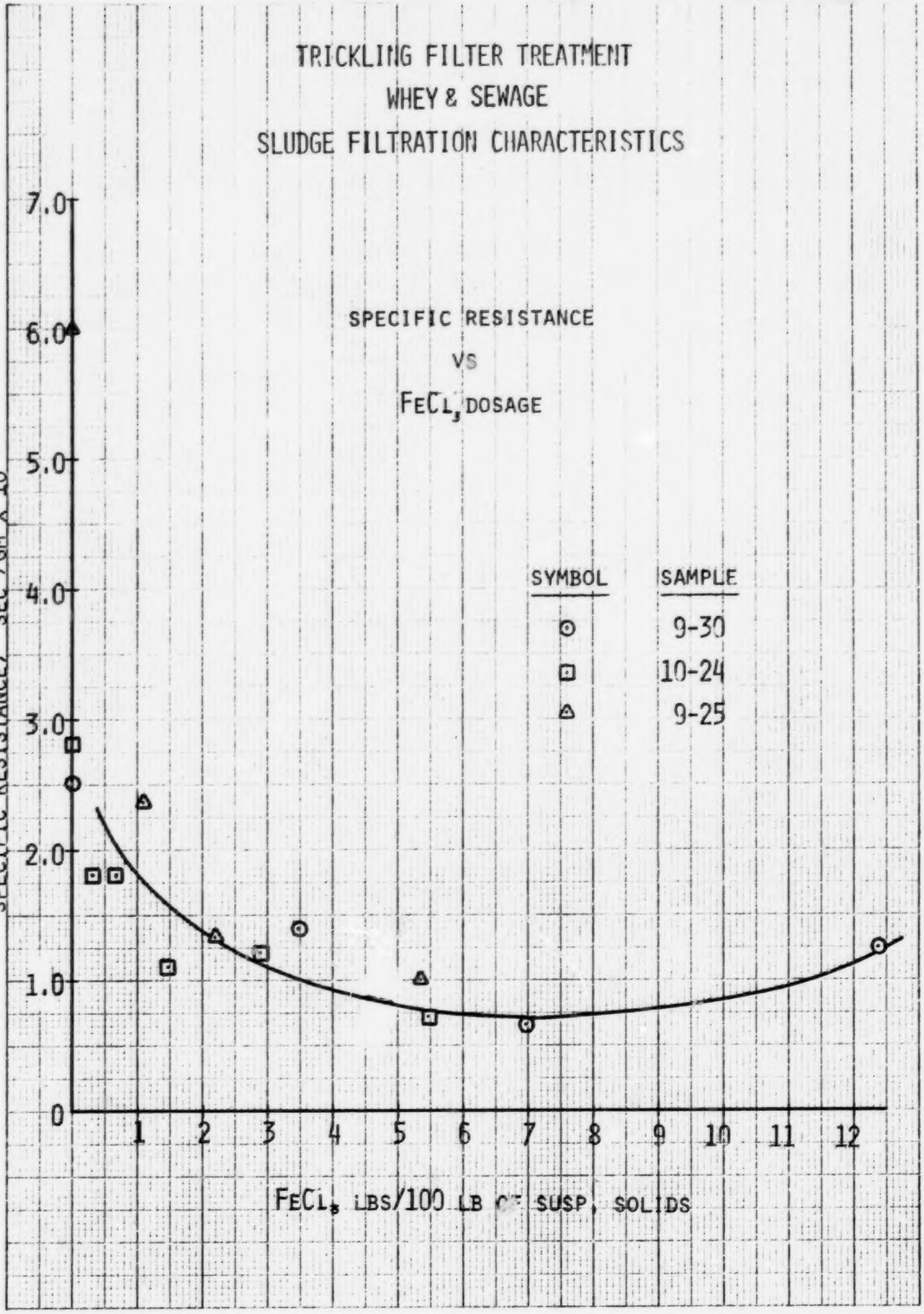
1. In order to maintain an SVI under 200, an organic loading of less than 0.1 lb BOD/lb Sludge/day is indicated for activated sludge.

2. Bench scale pilot plant operation indicated a sludge volume index of 145 when operating at a loading of 0.05 lb BOD/lb sludge/day. These low organic loading requirements may be compared with a nominal value of 0.25 lb BOD/lb sludge/day for municipal sewage operation at high degrees of treatment.

3. At an organic loading of 0.1 lb/lb/day, and using a design mixed liquor solids concentration of 2500 ppm, an aeration detention time of at least 10 hrs per 100 ppm of BOD is required for activated sludge operation at a SVI of 200 or less.

4. At an organic loading of 0.1 lb/lb/day, and a 2500 ppm mixed liquor, activated sludge aeration volume would be over 4-1/2 times the volume of a staged packed tower facility.

FIGURE 20


TRICKLING FILTER TREATMENT
WHEY & SEWAGE
SLUDGE FILTRATION CHARACTERISTICS
SPECIFIC RESISTANCE
VS
$FeCl_3$ DOSAGE
SYMBOL
SAMPLE
⊙ 9-30
⊡ 10-24
△ 9-25
SPECIFIC RESISTANCE, $SEC^2/GM \times 10^{-8}$
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
1
2
3
4
5
6
7
8
9
10
11
12
$FeCl_3$ LBS/100 LB OF SUSP. SOLIDS

5. Activated sludge settling characteristics were found to be periodically unstable at SVI values below 200.

6. Flotation of activated sludge mixed liquor, using bench scale equipment, indicated a design overflow rate of 600 gals/day/SF based on untreated waste flow. Flotation would not be economically competitive in comparison with sedimentation.

7. Activated sludge operation was observed to exhibit significant sensitivity to pH, nutrient and temperature control.

8. Waste sludge solids from the activated sludge process were not amenable to dewatering by vacuum filters or centrifuge.

PROCESS DESIGN FOR TRICKLING FILTRATION

Design loading for combined whey and domestic sewage are presented in Table 8. Whey contributions to the combined loadings are summarized as follows:

Flow	85%
BOD	97%
Solids	80%

Table 8. Treatment of Whey & Sewage Combined Loadings for Design

Characteristic	
1. Flow - mgd	1.17
- gpm	815
2. Suspended Solids - ppm	
Total	162
Volatile*	129
Inert	33
3. BOD - ppm	
Total	705
Suspended**	102
Dissolved	603

*Estimated from laboratory analysis of synthetic waste.
**Based on 0.63 lb BOD/lb SS measured in laboratory.

Suspended solids and BOD concentrations required in the treated effluent are shown on Table 9 together with the nominal percent removals required to achieve effluent limitations. Because of the high proportion of raw waste BOD in the dissolved form and the equally significant fraction of effluent BOD contributed by suspended solids discharged, the requirements for removal of dissolved BOD in the packed tower exceeds that of total BOD removal as measured between influent and effluent concentrations.

Process design procedures and design alternatives are presented for full scale packed tower trickling filtration below.

Filter Volume & Geometry

For a given type of packing, tower volume will vary with the following design parameters:

1. Liquid Application Rate
2. Recycle
3. Tower Height
4. Efficiency of BOD removal

The effects of variations in the first three parameters is dependent upon the necessity to maintain a minimum wetting rate. In all cases, an increase in efficiency of removal requires an increase in tower volume. In general, the effects of design parameters can be described as follows:

Design Variable	Change in Variables	Change in Tower Volume
Height - H	Increase	Decrease or no change
Recirculation ratio - r	Increase	Increase
Application velocity - U	Increase	Increase
Efficiency of Removal - E	Increase	Increase

Structural requirements and hydraulic distribution problems limit maximum tower height. Heights of 20 feet are common with maximums to 45 feet.

Commercial packing of the lattice structure type appears to require minimum application velocities of 1.0 gpm/sq ft. Operation below the minimum velocity can result in progressively less utilization of tower packing.

In order to maintain commonly used heights and provide a minimum application velocity, effluent recycle is usually required for high BOD removal efficiencies. The added tower volume required to accommodate recycle varies with the efficiency of removal sought.

Because of the non-uniform influences of design variables, process design calculations involve relatively complex manipulations.

Table 9. Treatment of Whey & Sewage
BOD & Solids Removals Required

Characteristic	
I. Effluent Required	
1. Suspended Solids - ppm	45
2. BOD - ppm	
Total	60
Suspended	28*
Dissolved	32

*Based on 0.63 lb BOD/lb SS as measured in laboratory

II. % Nominal Removals	
1. Suspended Solids	
Influent - ppm	168
Effluent - ppm	45
Removal - ppm	123
Removal - %	73.2
2. Total BOD	
Influent - ppm	730
Effluent - ppm	60
Removal - ppm	670
Removal - %	91.8
3. Dissolved BOD	
Influent - ppm	623
Effluent - ppm	32
Removal - ppm	591
Removal - %	94.9

Tower Volume

Equation 4 is rearranged to determine the wetting application rate (U) for tower operation using Surfpac of similar media without recirculation. Application velocity without use of recirculation is given the symbol U_o and is expressed as follows:

$$U_o = \frac{(K_T)\ (H)}{(2.3)\ \log\ (1-E)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

A maximum tower height of 42' is selected to minimize potential recirculation requirements and application rates, (U_o), are examined for parallel and series operation of filters. Series operation will reduce total tower volume requirements but will require additional pumping.

Application rates and stage removal efficiencies for single and multi stage designs are tabulated below:

	Single Stage	Two Stage	Three Stage
1. Efficiency/stage - E%	95	77.5	65
2. Application Rate without recirculation - U_o gpm/SF	0.42	0.85	1.23

Recirculation would be required on the single and two stage plants. Recirculation ratios are determined using a material balance for BOD taken across the trickling filter as follows:

$$r = \frac{\frac{(1)}{(1-E)} - (f)}{(f - 1)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

The value of (f) is determined by substitution into equation (4) using a minimum application velocity of U = 1.0 gpm/SF.

A tabulation of recirculation requirements versus stage design is then shown below:

	Single Stage	Two Stage	Three Stage
1. Efficiency/Stage-E%	95	77.5	65
2. Application Rate - gpm/SF	1.0	1.0	1.23
3. Recycle Ratio Required-r	6.6	0.4	0

A modification of the basic formulation is used to determine tower volume requirements. The modification is achieved by expressing tower volume requirements as a volume per unit of untreated flow (V') and relating this unit volume to process variables.

A material balance for flow is used to develop a definition for unit volume (V') as shown below:

By flow balance:

$$(1+r)\ Q = \frac{V \cdot U}{H}$$

and

$$V' = \frac{V}{Q} = (1+r)\ \frac{(H)}{(U)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

Unit volume requirements when recirculation is not required are designated by the subscript, o, i.e. V_o', and are determined from equation(8) by setting $r = 0$ and substituting into equation(8) the value of application rate (U) from equation(6) which results in the following design equation:

$$V_o' = \frac{2.3 \log\ (1/1-E)}{K_T} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

where: V_o' = CF of tower volume/gpm of untreated effluent when tower is not recirculated.

Unit volume requirements for a recirculation tower must be increased over that for a non-recirculated design because of the plug flow hydraulics of flow through the Tower. V' values are determined from equation(8) by setting $U = U_{min}$, e.g. 1.0 gpm/SF, and substituting into equation(8) the value of r as defined in equation(7). The design equation is stated as follows:

$$(V') = \frac{(H)}{(U_{min})} \cdot \frac{(E)}{\{(1-E)\ (f-1)\}} \ldots\ldots\ldots\ldots (10)$$

Using design equations(9) and (10) unit volume requirements for single and multi-stage tower designs can be compared as follows:

	Single Stage	Two Stage	Three Stage
1. Efficiency/Stage	95	77.5	65.0
2. Application Rate - gpm/SF	1.0	1.0	1.23
3. Recycle Ratio - r	6.6	0.4	0
4. Unit Volume - CF/gpm	320	116.8	102
5. Total Flow Pumped	7.6Q	2.8Q	3Q
6. Organic Loading* lb BOD/1000 CFD	22.8	64.5	73.0

*based on influent raw waste

Because of the high BOD removal efficiency required, a multi-stage plant is necessary to reduce tower volume. In the multi-stage design sedimentation of recycle flow prior to tower application is indicated to reduce media plugging tendency. Increased sedimentation capacity is then necessary for a multi-stage design. A comparison of the total capital cost for two and three stage design alternatives for: sedmentation; recycle pumping stations; and trickling filters was made as follows: (ENR = 1540)

1. Two Stage	$606,000
2. Three Stage	$596,000

The cost saving for a three stage design is within the accuracy of cost estimation and is thus, not significant. In order to eliminate a third pumping station as a maintenance center, the two stage design is selected.

Sludge Disposal Facilities

A material balance for waste treatment plant sludge solids is presented on Table 10.

Under design conditions 5060 lb/day of raw and biological solids from various conventional treatment units require disposal. An additional 1500 lb/day of chemical precipitate is anticipated as the result of lime addition to the final charifier. Lime addition is included to adjust effluent pH and to increase final clarifier solids removal by coagulation. Enhanced final clarifier solids removal is required to insure compliance with treated effluent BOD concentration

Table 10. Treatment of Whey & Sewage
Material Balance for Sludge Disposal
in pounds/day

Description	Design Condition
1. Influent Suspended Solids	1580
2. Effluent Suspended Solids	-420
3. Difference	1160
4. Biological Solids produced	3900
5. Sub-Total Raw & Biological Solids	5060
6. Conditioning Chemicals	355
7. Sub-Total Conditioned Solids	5415
8. Lime Precipitate Solids	1500
9. Total Solids for Disposal	6915

limitations. The provision for ferric chloride addition prior to dewatering increases solids loadings 355 lb/day. Total solids aggregate 6915 lb/day.

Waste solids disposal will employ dewatering and land-fill. Thickening of primary and secondary solids prior to dewatering will be required.

Based upon thickening studies, a solids loading of 6.5 lb/SF/day can be used to achieve an underflow solids concentration of 3.0 percent. A total thickener area of 1070 SF will be required to process the design solids loadings of 6915 lb/day.

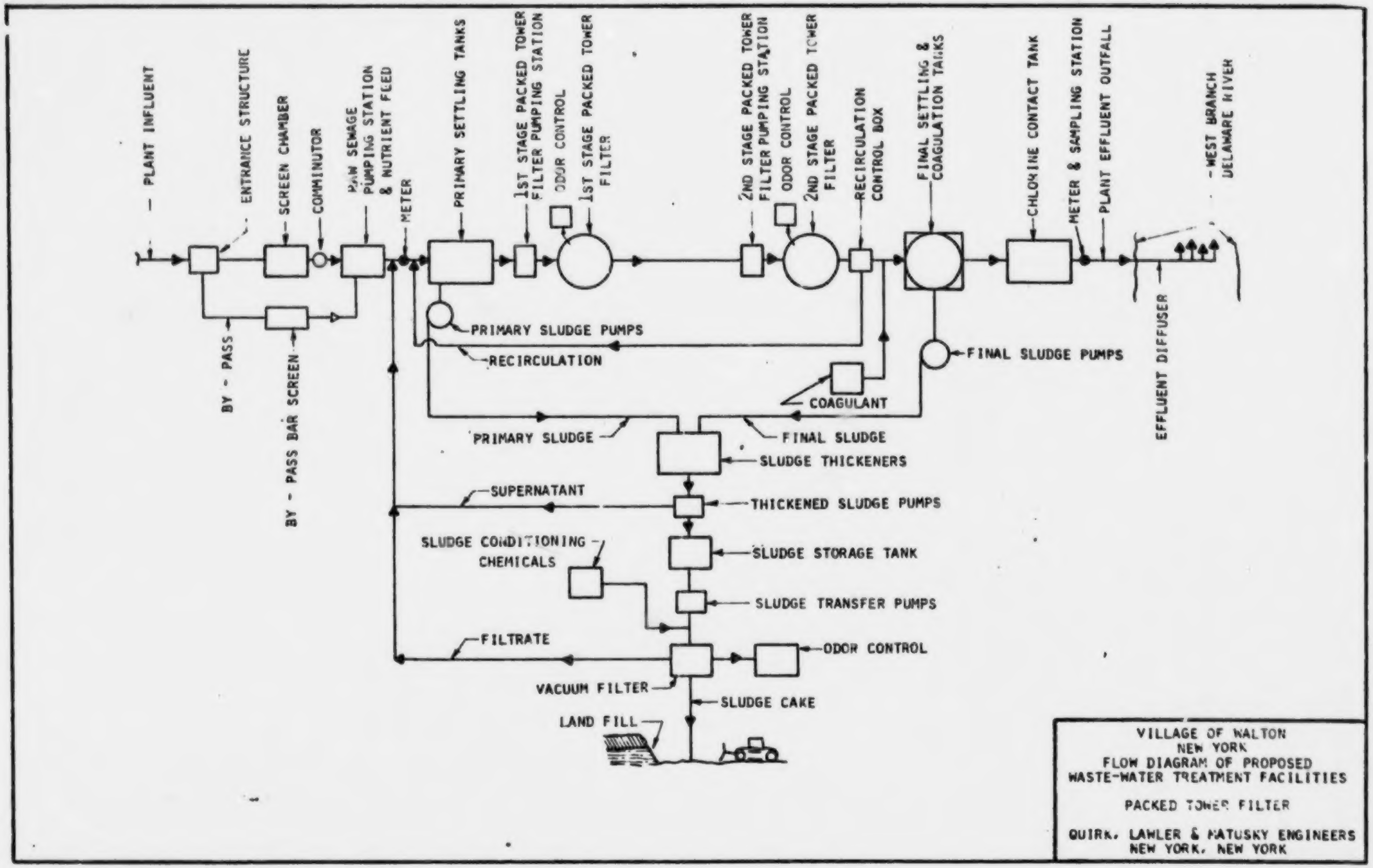
Sludge dewatering will be obtained by vacuum filtration. Laboratory and pilot plant studies indicate the use of a filter loading of 1.2 lb/SF/hr. Selection of a 6 hr/day filtration schedule will require two, 500 sq ft vacuum filters. Special ventilation facilities will be included to control odor levels in the filtration room.

Flow Sheet

A schematic flow diagram of the recommended waste water treatment facilities is shown on Figure 21. The system employs primary settling, two-stage packed tower trickling filters, final settling, coagulation, sterilization by chlorination, and sludge dewatering.

Grit removal facilities have not been provided because the raw waste is anticipated to contain virtually no grit and digesters (requiring grit protection) are not included in the sludge disposal system.

FIGURE 21



VILLAGE OF WALTON
NEW YORK
FLOW DIAGRAM OF PROPOSED
WASTE-WATER TREATMENT FACILITIES

PACKED TOWER FILTER

QUIRK, LAWLER & MATUSKY ENGINEERS
NEW YORK, NEW YORK

The screened influent will be pumped and metered to the primary settling tank influent distribution chamber and mixed with a recirculation flow from the 2nd stage packed tower. The combined flow will continue through the primary tanks. The effluent from the primary settling tanks is pumped up to the 1st stage packed tower distributor. This 1st stage effluent is pumped to the 2nd stage packed tower distributor, about 50 percent of the effluent of the 2nd stage packed tower will be returned as a recirculation flow to the influent distribution chamber of the primary settling tanks. The process flow stream continues through the final settling and coagulation tanks, chlorine contact tank and is finally diffused in the receiving waters.

Sludge from the primary and final settling tanks and coagulation tanks is pumped to sludge thickeners.

The sludge thickener underflow will be stored in a sludge storage tank prior to dewatering. The sludge cake will be disposed in a sanitary land fill.

The treatment of whey bearing waste and its sludge dewatering is associated with objectionable odors. Covers will be provided for the packed towers and odor control ventilation equipment would be provided.

An architectural rendering of the complete treatment facilities is presented as Figure 22.

Capital Costs

The division of capital cost for treatment of whey and sewage is based upon their relative contributions of four major design loading parameters and a detailed allocation of the capital cost of each major treatment unit among the loading parameters.

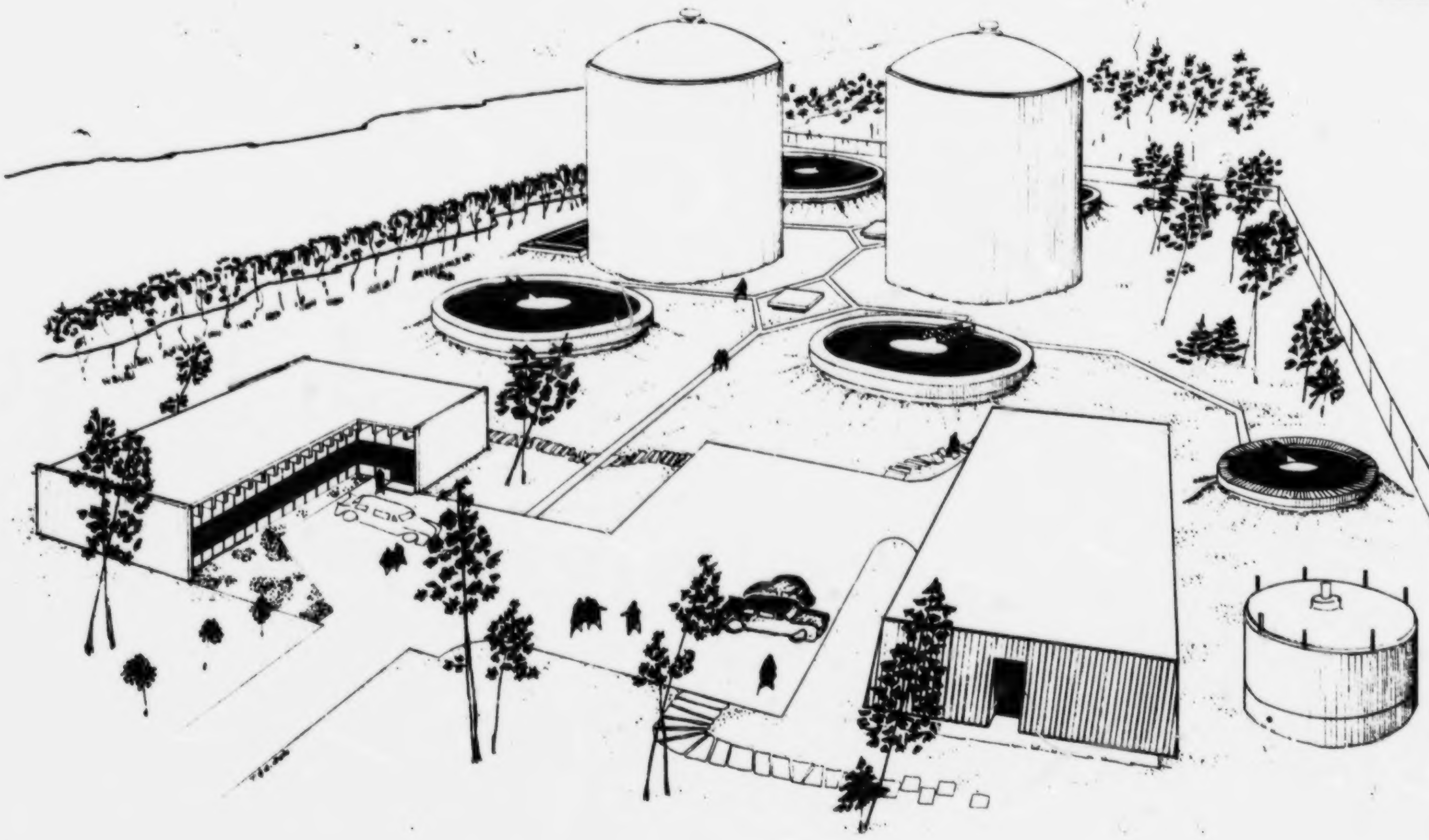
The procedure assigns the cost of a unit to the design parameter (s) which determines the capacity of the particular unit operation. Allocation of the capital costs of sludge disposal facilities is made between suspended solids in the untreated waste and suspended solids generated from BOD removal. Solids generated from final clarifier coagulation are allocated to BOD.

Treatment plant items which cannot be attributed to a specific design loading, such as administration building, are pro rated among the design loading parameters based on the allocations achieved for all other units. Cost allocations are also presented in terms of capital cost (ENR = 1540) per unit amount of each design loading i.e.

$139,500 /mgd of peak hourly flow
$360,000 /mgd of average daily flow
$272/lb/day of dissolved BOD
$134/lb/day of suspended solids

FIGURE 22

WALTON
MUNICIPAL
WASTE WATER
TREATMENT
PLANT



QUIRK,
LAWLER &
MATUSKY.

engineers

New York, N.Y.

These unit capital costs do not include credit for a 60 percent construction grant applicable to the facility.

TRICKLING FILTRATION OF WHEY EFFLUENT - SUMMARY

1. Trickling filtration of whey effluent and whey effluent mixed with sewage has been shown to be an effective treatment method both on absolute terms and on a relative basis when compared with activated sludge.

2. A comparison of whey treatability with that of other industrial effluents, demonstrates that whey treatability compares well with that of the average industrial effluent when packed tower trickling filters are employed.

3. Nutrient additions other than ammonia nitrogen were not productive of increased rates of bio degradability. The addition of ferrous iron did not, as anticipated by other investigators, result in an increased treatability.

4. Nitrogen addition resulted in a 40 percent increase in the rate of BOD removal.

5. The inherently acidic reaction of a whey effluent was shown to have no adverse effect on trickling filtration performance using high porosity media. pH variations from 7.0 to 4.5 were not detrimental but, rather resulted in an increase of BOD removal rate as pH decreased. pH increases above 7.0 were shown to result in a reduction of BOD removal rate. Although these comments are based on limited data the trend of pH influence appears clear.

6. Trickling filter operating variables of: temperature, recirculation and hydraulic application rate have been quantified in a verified, process design model(39) summarized in this paper. While the number of implications which can be drawn from a sensitivity analysis of the model are too extensive to be within the scope of this study, several qualitative comments can be made as follows: (a) Increased temperatures are beneficial for process performance. (b) Recirculation should be included only to insure adequate application velocities and not to provide additional removal efficiency. (c) The inclusion of recirculation will require provision for additional filter volumes which will normally out weigh the effects of repeated application. (d) The need to maintain application velocities sufficiently high to insure adequate wetting of packing media will require towers of maximum practicable height or stage treatment to provide high BOD removals, economically. This latter requirement is dictated by media characteristics rather than whey characteristics.

7. Trickling filter performance will be sensitive to flow variation rather than BOD variation. Response times of from 6-24 hours should be experienced after a significant change in hydraulic application rate. Under normal operating conditions, filter performance should be stable.

8. Filter sludge growth will be prolific and will require a high porosity media of low susceptibility to retention of sloughed filter slime to avoid plugging.

9. Filter odors should not be offensive at organic loadings requested for high BOD removals. However, filter installation should be provided with covers if proximate to odor senstive areas.

10. Final sedimentation of filter effluent may require coagulation for production of a low solids effluent and/or for removal of suspended BOD to insure an overall plant performance above 90 percent BOD removal.

11. Secondary sludge can be thickened using gravity equipment, however, thickener requirements will be significantly greater than that used for domestic sewage.

12. Dewatering of secondary sludge can be accomplished by vacuum filtration. Centrifugation performance would be poor and would not be recommended. Vacuum filtration characteristics of trickling filter sludge exceed, significantly, those of activated sludge. Dewatering requirements may well control the selection of the BOD removal process.

METHANE FERMENTATION OF WHEY

by

C. D. Parker,*

INTRODUCTION

Disposal of wastewater from the manufacture of dairy products, butter, cheese, casein, powdered and condensed milks in Australia has created problems of odour nuisance and water pollution.

In 1964 the Australian Dairy Produce Board Research Fund sponsored a research project at this Institute to study ways and means of developing low cost treatment of these wastes to obviate the problems created by their disposal.

The project included a survey of existing methods of disposal, the identification of the flow and composition of wastes from individual processing operations and the experimental operation of treatment facilities to treat general factory waste and undiluted whey by lagoons, oxidation ditch and methane fermentation.

The disposal of undiluted whey arising from the manufacture of cheese from whole milk and casein, from skim milk is a problem in many parts of the world.

The annual production of whey in Australia is 800 million gallons per year, an average value of 2.2 million gallons per day. It is typical of the dairy industry in Australia that there is a marked seasonal variation in milk production and the discharge of whey. In some cases the peak/minimum intake ratio is as high as 14/1. Peak production occurs in spring in the period September to December. The production of whey during the peak period would be of the order of 6 million gallons per day.

Many of the larger factories which basically produce butter are capable of considerable flexibility in handling the skim milk. It may be acidified and casein of various grades recovered and dried, or it may be dried direct as powder either by spray or roller drying.

By far the greatest source of problems associated with whey disposal is whey from casein manufacture.

EXISTING METHODS OF DISPOSAL IN AUSTRALIA

In Australia at present there is very little recovery of milk solids from whey. One or two factories have dried cheese whey and powdered it

---

*Melbourne Water Science Institute, Australia.

Preceding page blank

on roller driers, an attempt was made to recover lactose but this has been abandoned.

Almost the whole of the 800 million gallons produced is either discharged with the general factory waste flow, tankered to pig farmers or spread over areas of waste land.

In some cases factories establish their own piggeries as a means of disposing of whey. Because of the seasonal variation in whey production it is not possible to rely on a regular level of supply for pig food and in any case whey must be supplemented by other solid feed. As a result it is seldom possible to dispose of the whole of the whey produced to farmers at peak production. At a typical factory run piggery with a peak whey production of 65,000 gallons per day over half cannot be used for pig food and supplemental methods of spray irrigation are required.

In a few cases whey has been spread or spray irrigated over pasture or bare land but the areas required are considerable. The maximum permissible rate of application appears to be on the order of 500-1000 gallons per acre per day and often this needs to be diluted 2-3 times with factory waste if the pasture is not to be damaged.

Whey utilization for the recovery of milk solids by yeast fermentation, reverse osmosis and electrodialysis is currently being examined but so far no experimental or commercial installations have been constructed.

METHANE FERMENTATION OF WHEY

Digestion of sewage sludge solids by the sludge digestion process is a well established sewage treatment procedure.

In the digestion process solids are fermented first to volatile organic acids by a variety of heterotrophic bacterial types and these acids are then converted to methane and CO_2 by specific methane forming bacteria.

Schroepfer and others have shown how this process can be adapted to the purification of high B.O.D. wastes from meat processing, in heated digester type units.

Oswald and others have shown how the same process of methane fermentation is involved in the reduction of B.O.D. of similar wastes in anaerobic type lagoon installations.

Our own work (Parker 1967) on fruit and vegetable canning waste has shown how the same mechanism can be used to reduce the high B.O.D. of these wastes, also in anaerobic type lagoons.

The B.O.D. of whey is 35-40,000 ppm. very much higher than any of the above wastes treated in this way, the composition of cheese and casein whey is shown in Table 1.

Table 1 Composition of Whey

	Casein Whey	Cheese Whey
B.O.D. ppm.	40,000	36,000
pH	4.3	4.8
Titratable acidity (meq./l.)	45	53

As part of the research project studies were made to determine whether whey could be fermented to methane and CO_2 in admixture with fermenting sewage sludge or alone.

Fermentation with Sewage Sludge

At the Moe Sewage Treatment Works there were available two heated sludge digesters with facilities for measurement of gas yield from each independently.

Because of excess digester capacity it was feasible to make one available for a trial fermentation of whey with digested sewage sludge The digester capacity was 42,000 gallons and the normal sludge load 2000 gallons per day. This was reduced to 500 gallons per day and a daily addition of casein whey added. The casein whey was transported daily by tanker to the sewage treatment works and stored in a 1000 gallon tank.

A concrete pit was constructed into which the unneutralized undiluted whey could be measured. By valve the required daily addition could be allowed to flow into a second pit together with digested sludge drawn from the bottom of the digester. The mixed contents of the second pit were then pumped back through the normal raw sludge inlet to the digester. In this way effective mixing of the whey with the digester contents was achieved.

Over a period of nine months, daily additions of whey were made, the gas yield measured and samples of digested sludge and supernatant liquor examined at weekly intervals.

Over this period, normal gas production continued and analysis of the supernatant liquor displaced daily, showed that the B.O.D. was 300-400 ppm.

The maximum rate of whey addition achieved was 500 gallons per day representing a B.O.D. loading of 0.026 lbs.B.O.D./cu. ft./day, a value about 2/3 the usual design capacity for digesters. This represented a detention time of 80 days.

Owing to demands on the plant for normal sewage sludge digester the experimental loading had to be discontinued before breakdown of the digestion process occurred.

This study showed that provided effective premixing of the whey with the digester contents was achieved substantial destruction of whey B.O.D. could be brought about (99 percent) by methane fermentation. Analysis of the digester gas produced showed this to be of a normal value of 65 percent methane, 35 percent CO_2.

Fermentation of Undiluted Whey

In view of the success of the Moe sludge digester operation an attempt was made to maintain a successful fermentation in the laboratory without any sewage sludge feed.

The fermentation was carried out in a one gallon glass jar. The fermenter was housed in an incubator held at 95° F. Fermentation was initiated by using 500 ml of digested sludge from the Moe digester and the jar filled to the overflow level with water. Small daily additions of unneutralized undiluted casein whey were made and these slowly increased in volume.

Gas yield was measured daily and the supernatant liquor, displaced daily, was analyzed once a week.

The maximum daily addition achieved without upset to the fermentation was 250 ml. of whey per day. This represented a detention time of 16 days and a B.O.D. loading of 0.13 lbs.B.O.D./cu. ft./day. This was maintained for over 3 months without upset to normal fermentation. Gas yield at this maximum loading rate was 31 volumes of gas per unit volume of whey (5 cu. ft. per gallon). Analysis of the gas showed the normal methane content throughout the period of observation. Apart from the initial addition of seed sludge no further solids addition was made.

The supernatant displaced by the added whey had the composition shown in Table 2.

Table 2

	Whey Added	Supernatant Liquor Displaced
B.O.D. ppm.	36,000	450
Ammonia-Nitrogen	15	450
pH	4.3	6.9

By prior neutralization of the whey to 7.0 the maximum load could be increased 10 percent. Cheese whey could be fermented equally well as casein whey.

To determine the feasibility of the process on an experimental scale a 500 gallon fermenter was constructed and fed entirely with casein whey.

The fermenter was heated externally through an electrically heated heat exchanger. The temperature of the contents were maintained at 95°F. The contents of the fermenter were pumped continuously through the exchanger, whey was introduced at a slow rate continuously by a peristaltic pump into the recirculated fermenter contents. Only the lower third of the fermenter contents were circulated. The fermenter was initially seeded with 50 gallons of digested sludge from the Moe digester. It was found that by displacing the outflow from the top water level in the fermenter very little solids are discharged. There is maintained a constant volume of solids in the fermenter and addition of sludge solids is not needed. Provision was made for settling solids out of the outflow and their return by pump to the fermenter. In fact there was found to be no need for this recovery of solids as a clear outflow was obtained.

Gas was led off the top of the fermenter and measured through a domestic type gas meter.

The rate of whey addition was slowly increased. At the completion of the research project period this had been increased to 60 gallons per day, a detention period of 6-7 days. Owing to expiring of the grant the load was not increased to bring about failure of the fermentation process.

At this maximum rate of whey addition operation was continued for two months and the composition of the outflow was as shown in Table 3.

Table 3 Experimental Fermenter Outflow

	Whey	Outflow
B.O.D. (ppm.)	36,000	450
pH	4.2	7.0

It can be concluded that with a detention of 6-7 days and probably with a detention of about 5 days a B.O.D. reduction of 99 percent can be obtained if the fermentation is carried out under the conditions described. The gas yield confirmed the laboratory value of 5 cu. ft. per gallon of whey.

ANAEROBIC LAGOON TREATMENT

Whey can be successfully treated without nuisance by daily addition to an anaerobic type lagoon in which algal growth is well established in the upper layers of the pond.

In these investigations it was found that with a pond 30 ft. square and 5 ft. deep a regular daily addition of undiluted whey could be made at a B.O.D. loading of 400 lbs./ac./day. Under these conditions such a pond could be operated for two years without nuisance.

The B.O.D. of the pond contents averaged 250 ppm. and the pH was maintained in the range 6.5-7.5.

The detention time with such a loading is of the order of 1000 days which in practice would mean that there is no outflow. An outflow could be achieved if the whey were to be diluted with general factory waste.

DISCUSSION

These investigations have shown that subject to careful observance of loadings and optimum conditions for the appropriate microbiological fermentations, the B.O.D. of whey can be reduced substantially by methane fermentation either in admixture with sewage sludge in a conventional sludge digestion unit alone at much higher rates by continuous culture fermentations or in anaerobic type lagoons in the presence of an algal population.

The costs of treatment depend on the size of the operation and a number of other factors. To treat a peak whey discharge of 20,000 gallons per day based on Australian construction costs, by lagoons or in separate whey fermenters would be as shown.

LAGOONS

Loading rate:

1st. stage - 400 lbs.B.O.D./ac./day (85 percent removed)
2nd. stage - 60 lbs.B.O.D./ac./day with 1/1 recirculation of 2nd. stage effluent to inlet first stage.

Lagoon areas:

1st. stage - 18 acres.
2nd. stage - 16 acres.

Land 40 acres @ $500 per acre	$20,000
Earth works involved 13,600 yds. @ 40 cents/yd.	$ 5,440
Pipeline 2700 ft.	$ 3,000
Recirculation pump	$ 500
	$28,940

WHEY FERMENTER

Digester requirements: 100,000 gallon capacity at loading of 20,000 gallons per day.

Process requires continuous addition of raw whey, continuous recirculation of contents maintained at 85°-90°F., and overflow of effluent from near surface. Raw and recirculation addition to be made at base of tank inducing circulation of contents. Recirculation draw off from centre tank one third up from base. Overflow to pass over weir in inspection pit on wall.

Optimum conditions expected to reduce B.O.D. from 36,000 - 400 ppm. and produce 5 cu. ft. per gallon per day "methane" gas.

For full scale plant of above capacity, the digester proposed would be of mild steel construction, located above ground with suitable insulation, and floating gas holder cover. Raw whey would be pumped from whey storage to a header tank. The contents would be recirculated by pumping through a heat exchanger which would be fired by gas evolved in the process with fuel oil as standby heating fuel.

The gas system required would comprise the gasholder cover with flame trap and safety valve; pipework and meter to the heat exchanger; pipework, meter, regulator valve and flame trap to a waste gas burner for disposal of excess gas; and necessary sediment and moisture traps.

Recirculation pump, heat exchanger, switchgear and pressure gauges would be located within a weatherproof housing.

Item	Mild Steel 100,000 gal. floating cover digester
1. Construction of Digester	$ 40,000
2. Insulation	$ 3,400
3. Heat Exchanger	$ 6,000
4. Gas Equipment	$ 4,000
5. Recirc. & Delivery Pumps	$ 1,000
6. Pipework and Valves	$ 1,700
7. Housing	$ 200
8. Electrical	$ 800
9. Raw Whey Storage	-
10. Modifications to Digester	-
	$ 57,100
Provisional Sum 10 percent	$ 5,710
Engineering & Supervision 10 percent	$ 5,710
	$ 68,520

It should be emphasized that both the methods propounded for methane fermentation of whey have only been demonstrated on a very small scale. Both need to be operated as a large scale demonstration unit before they can be accepted as a reliable and economic method of treatment.

STATE OF THE ART OF DAIRY FOOD PLANT WASTES AND WASTE TREATMENT*

by

W. James Harper and John L. Blaisdell**

The dairy food industry is an important part of the overall food industry of this country and contributes materially to fluid wastes which must receive treatment prior to their discharge to streams and other waterways.

The industry has been in a dynamic state for the past several decades with major changes occuring within the industry. During this period of time, there has been a slight increase in the amount of milk shipped from farms for processing, a material decrease in the number of plants processing dairy foods, a very significant increase in the amount of milk processed by each plant, and a major trend towards automation and mechanization. These changes have significantly increased the waste load per plant. Under prevailing practices, waste loads per plant can be expected to range from 2000 to 10,000 pounds of BOD per day.

The trend over the last several years for reduced milk production appears to be reversing in that the amount of product being processed has actually increased from 104 billion pounds in 1960 to 108 billion pounds in 1969, whereas the total production of milk on the farm changed from 123 billion pounds in 1960 to 116 billion pounds in 1969.

This paper reports a comprehensive study of the present status of dairy wastes, in respect to composition, control and treatment based on literature reports and current industrial knowledge and practice. Little research in respect to dairy food plant wastes and waste treatment has been conducted in this country in the past decade, except that which has centered around the visible whey disposal problems that are the subject of other papers at this conference. An attempt was made to supplement our literature knowledge with information gained from current industrial experience. A survey was made of all major proprietory and cooperative dairy food firms in this country, and information was obtained on current knowledge of about 697 plants in 38 states. These plants comprise about 11 percent of the total dairy food plants in the country, but process more than 65 percent of the total milk supply. In addition, plant visitations were made to 30 dairy food plants. A major

---

* Supported by Grant No. 12060-EGU from the Water Quality Office of the Environmental Protection Agency of the U. S. Government.

**Department of Dairy Technology, The Ohio State University, Columbus, Ohio.

Preceding page blank

emphasis was placed on the large, modern and automated plant, since these types of operations are becoming the dominant type of dairy food plant operation, and these large operations can be expected to continue to increase. The significance of these plants can be illustrated by the fact that 10 of the plants visited process about 2 percent of all the milk produced in this country at the present time.

Industrial Knowledge of Waste Loads

During this investigation, effort was made to assess the knowledge of the dairy food industry in respect to the knowledge that the industry has of its waste load in terms of BOD, COD and suspended solids. Information in respect to number of plants with (a) knowledge of waste loads, (b) paying surcharge on waste composition, (c) their own treatment facility and (d) waste water discharges to municipal sewer systems is summarized in Table 1. Only about 11 percent of these plants had any knowledge of their BOD_5 in their waste water and only 7 plants possessed any knowledge of COD. Knowledge of BOD_5 loading was directly related to those plants who had either been cited for recent violations, had their own treatment facilities or were paying a surcharge on waste composition. Payment of a surcharge on waste composition and operation of its own treatment facility, however, was no guarantee of knowledge of the BOD_5 by an individual plant. One national organization operating several treatment facilities indicated that it did not measure BOD_5 on the raw or treated waste and utilized only visual inspection as a means of evaluation. Approximately 90 percent of all the dairy plants surveyed discharged their waste water to a municipal treatment facility.

Generally, the dairy food industry knows the problem of fluid waste and waste treatment will have to be faced, but has not taken the initiative in solving the problem and with a few exceptions it appears that the industry will not take remedial steps until forced to do so by legal and/or economic pressures.

A major reason for the passiveness of the industry is economic. Because of low profit margins, the expenditure of funds for non-economic terms has been avoided. The concept that the dairy food industry must consider water pollution control as an intrical cost of doing business, like any other production item, has not been accepted. In addition to economic, other reasons for industry's passive attitude are (a) a broad lack of knowledge of the nature and strength of dairy food plant waste, (b) a failure to understand the potential economic value in recovering wastes and converting them to usable by-products, and (c) a general lack of understanding of the technology of waste control and treatment. Numerous members of the industry who are not currently involved with operating waste treatment facilities or paying surcharges on BOD_5 or other waste composition components, have little understanding of BOD, and most have never heard of COD. As municipalities increase the practice of charging the industry for its waste on a compositional basis and/or impose legal

Table 1. Summary of Knowledge of Dairy Food Plant Waste Water Loads by the Dairy Food Industry

Plant Type	No. of Plants	% of plants with			
		Knowledge of waste loads (BOD)	Payment on basis of BOD	Treatment plants for own wastes	Waste discharge to city
National and Regional Proprietory Companies	320	12.8	5.0	9.1	91.0
Local Proprietory Companies	234	11.7	8.5	6.8	95.7
Cooperatives	93	6.4	8.6	10.7	51.6
Total	647	11.5	6.8	8.6	87.1

limits on waste composition going to municipal treatment facilities, the industry will take a more active role in fluid waste control. An active nationwide educational program is needed to influence attitudes, to provide a sound technological basis for controlling the pollution problems of the dairy industry of the future.

Dairy Plant Wastes

Industrial wastes from dairy plants consist primarily of varying quantities of water born milk solids from a variety of sources, detergents, sanitizers and lubricants and domestic wastes. The quantity and strength of the waste water discharged from the dairy food plants vary widely depending upon the quantity of water utilized, the type of process in the operation, and the control management exerts over various waste discharges.

Information concerning the composition of the dairy food plant wastes was obtained from both literature and from industrial sources. Prior to quite recently, the majority of available information in respect to dairy food plant waste water composition was limited to BOD, suspended solids and COD. Very limited information on dairy food plant waste water is available for temperature, pH, fat, protein, carbohydrates and other components such as phosphates, chloride, sulphur, surfactants and sanitizers.

Dairy Food Composition and BOD

The biological and chemical oxygen demand of milk plant waste water will vary as a function of the products manufactured since differences occur in the amount of oxygen that is required for the oxidation of different constituents such as fats, carbohydrates and protein. Various dairy products differ widely in their relative concentrations of major organic constituents and an understanding of the composition of various fluid dairy foods is essential to a full understanding of dairy plant wastes. The constituents of primary concern in water pollution for various dairy products are cited in Table 2. These values are based upon current average compositional values and vary somewhat in previously cited compositional data for dairy products in earlier waste guides(4).

Reported BOD values for various milk constituents and other organic components that may be present in dairy food plant waste waters are listed in Table 3. The major three constituents of milk contributing to BOD are lactose, milk fat and milk proteins with BOD_5/lb of component averaging 0.65, 0.89 and 1.03 respectively. Utilization of these figures permits the calculation of BOD and the relative contribution to BOD by various constituents. Calculated values, literature values and percentage contribution of milk components to BOD in different products are cited in Table 4 for most common dairy foods. Except for whey, the calculated and literature values are in close agreement.

Table 2. Average Composition of Milk and Milk Products (100 g.)

Product	Fat g.	Protein g.	Lactose g.	Lactic Acid g.	Total Organic Solids g.	Ca mg.	P mg.	Cl mg.	S mg.	Total Ash g.	Viscosity (c.p. at 20°C)
Skimmilk	0.08	3.5	5.0	-	8.56	121	95	100	17	0.7	1.4
2% milk	2.0	4.2	6.0	-	12.2	143	112	115	20	0.8	2.4
Whole milk	3.5	3.5	4.9	-	11.1	118	93	102	19	0.7	2.2
Half & half	11.7	3.2	4.6	-	19.5	108	85	90	16	0.6	7.5
Coffee Cream	18.0	3.0	4.3	-	25.3	102	80	73	12	0.6	15.0
Heavy cream	40.0	2.2	3.1	-	45.3	75	59	38	9	0.4	25.2
Choc. milk[a]	3.5	3.4	5.0	-	18.5	111	94	100	19	0.7	15.0
Churned Buttermilk	0.3	3.0	4.6	0.1	8.0	121	95	103	15	0.8	1.5
Cultured Buttermilk	0.1	3.6	4.3	0.8	10	121	95	105	17	0.7	500
Sour cream	18.0	3.0	3.6	0.75	24.6	102	80	73	12	0.6	10000
Yoghurt[b]	3.0	3.5	4.0	1.1	10.8	143	112	105	19	0.7	3000
Evap. milk	8.0	7.0	9.7	-	27	757	205	210	39	1.6	30
Ice cream[c]	10.0	4.5	6.8	-	41.3	146	115	104	20	0.9	35.0
Whey	0.3	0.9	4.9	0.2	6.3	51	53	195	8	0.6	1.4
Cot. cheese Whey	0.08	0.9	4.4	6.7	6.1	96	16	95	8	0.8	1.3

Organic Ingredients Added

a. Sucrose, 6% & chocolate solids, 1%

b. Fruits

c. Sugar, 15%

Table 3. Reported BOD Value for Various Milk Constituents And Related Constituents

Constituent	Pound BOD_5 / Pound Component	
	Range	Average
Lactose	.42 - .72	.65
Glucose	.53 - .78	.66
Lactic Acid	.63 - .64	.63
Milk Fat	.70 - .95	.89
Glycerol	.65 - .83	.75
Butyric Acid	.34 - .90	.75
Sodium Butyrate	-	.41
Palmitic Acid	-	1.07
Sodium Palmitate	0.4 - 1.02	.70
Stearic Acid	-	.80
Sodium Stearate	.45 - 1.70	1.20
Milk Proteins	.60 - 1.20	1.03
Casein	.25 - 1.17	1.04
Hydrocolloids		
Sodium Alginate	-	0.36
Carboxymethyl-cellulose	-	0.30

Table 4. A Comparison of Literature and Calculated BOD_5 Values and Percentage Contribution of Milk Components to Product BOD_5

Product	Literature BOD_5	Calculated BOD_5	% Contribution to BOD_5 by Milk Fat	Milk Protein	Lactose	Lactic Acid
Skimmilk	67,000	73,000	6.3	49.3	44.5	-
2% milk		100,000	17.8	43.3	39.0	-
Whole milk	104,000	99,000	31.5	36.4	32.2	-
Half and half	156,000	167,000	62.4	19.7	17.9	-
Coffee cream	206,000	219,000	73.1	14.1	12.8	-
Heavy cream	399,000	399,000	89.2	5.7	5.0	-
Choc milk	-	145,000	21.5	24.2	22.4	-
Churned buttermilk	68,000	71,000	4.2	48.2	46.7	0.98
Cultured buttermilk	-	64,000	1.3	52.2	39.4	7.1
Sour Cream	-	218,000	73.5	1.4	10.7	21.7
Yoghurt	-	91,000	27.8	37.6	27.1	7.2
Evaporated milk	208,000	206,000	34.6	35.0	30.6	-
Ice Cream	292,000	290,000	30.7	15.9	15.2	-
Whey	34,000	45,000	5.9	20.6	70.8	2.8
Cottage cheese whey	31,500	42,000	1.6	22.1	68.1	10.5

BOD_5 and Waste Water Volume Coefficients of Commerical Dairy Food Plant Wastes

The strength of dairy food plant waste waters has been reported generally in terms of part per million of BOD, without regard to total waste water volume or the relationship of the amount of milk processed; and waste volumes are often reported irrespective of the volume of product processed. Waste water volume and strength coefficients have been calculated from industrial and literature data in respect to the amount of milk, or milk processed. For the purpose of this paper, the waste coefficients are defined as follows:

$$\text{Waste Water Volume Coefficient (WWVC)} = \frac{(\text{gal. waste water x } 8.34)}{(\text{gal. milk processed x } 8.6)} =$$

pounds of waste water/pound of milk processed

$$\text{Waste Water Strength Coefficient} = \frac{\text{pounds } BOD_5\text{/day}}{\text{pounds milk processed/day x } 1000} =$$

pounds BOD_5/1000 pounds of milk processed

A summation of literature values for waste water coefficients for various types of dairy food plant operations are shown in Table 5. The use of volume as a reference for the coefficients eliminated the "yield" variable for different products and brings the coefficients into relatively close agreements for different types of dairy food plants.

Through personal contacts and plant site visitation, information on dairy plant wastes and waste treatment was obtained for 57 plants in terms of milk volume processed, gallons of waste water produced, and ppm BOD_5. The pounds of BOD per day, volume coefficient and BOD coefficients were calculated (Table 6). All of the plants surveyed used either advanced technology or a mixture of advanced and typical technology with 30 of the 57 plants manufacturing more than one type of dairy product. Statistical analyses indicated no significant difference in BOD or volume coefficients and the type of plant operation; except that BOD coefficients of the plants processing milk plus cottage cheese and ice cream had significantly higher coefficients than the other type of operation. Coefficients were unrelated to plant size or to the degree of automation. Plants that were fully automated in respect to processing and CIP systems frequently had higher than average volume and BOD coefficients. The wide variability of both volume and BOD coefficients among plants of similar technologies and size and a lack of correlation between waste coefficients suggests that the controlling factor in waste volume and BOD coefficients was management related. Based on site visits for 20 plants, the evaluation was made of management practices and coefficients. These are tabulated in Table 7. The data

Table 5. Summary of Literature Values of Waste Water Coefficients*

Products Mfg.	No. of Plants	Waste Volume Coef.		BOD_5 Coef.	
		Range	Average	Range	Average
Milk Receiving	6	4.6 - 12.5	6.1	0.02 - 4.8	1.0
Milk	11	1.5 - 18.6	4.9	1.1 - 22.0	5.2
Butter	2	1.4 - 8.3	4.85	0.8 - 2.1	1.46
Cheese	12	0.3 - 5.1	2.06	0.2 - 4.1	1.8
Condensed	2	1.2 - 2.3	1.75	1.0 - 1.9	1.45
Powder	10	0.8 - 11.5	2.8	0.6 - 12.3	8.9
M. CC. IC.	2	0.8 - 1.2	1.0	0.6 - 0.9	0.7
Mix Prod.	5	1.1 - 6.8	1.2	1.3 - 3.2	1.9
Total	46	0.3 - 18.6	3.9	0.2 - 22.0	2.6

* Volume coefficient in #/# milk processed, BOD_5 coefficient in #BOD_5/1000 #milk or milk equivalent received.

Table 6. Summary of Commerical Plant Survey for Waste Water Coefficients*

Products Mfg.	No. of Plants	Waste Vol. Coef.		BOD Coef.	
		Range	Average	Range	Average
Milk	6	0.1 - 5.4	3.25	0.2 - 7.8	4.2
Cheese	3	1.63 - 5.7	3.14	1.0 - 3.5	2.04
Ice Cream	6	0.8 - 5.6	2.8	1.9 - 20.4	5.76
Cond. Milk	2	1.0 - 3.3	2.1	0.2 - 13.3	7.6
Butter	1	-	0.8	-	0.85
Powder	2	1.5 - 5.9	3.7	0.02 - 4.6	2.27
Cottage Cheese	3	0.8 - 12.4	6.0	1.3 - 71.2+	34.0
Cottage Cheese & Milk	19	0.05 - 7.2	1.84	0.7 - 8.6+	3.47
Cottage Cheese Ice Cream & Milk	9	1.4 - 3.9	2.52	2.3 - 12.9	6.37
Mixed Products	5	0.8 - 4.6	2.34	0.9 - 6.95	3.09
Overall	56	0.1 - 12.4	2.43	0.2 - 71.2	5.85

*See footnote 1, Table 5

+Whey included, whey excluded from all other operations manufacturing cottage cheese

Table 7. The Effect of Management Practices on Waste Coefficients

Plant No.	Products Manufactured	Milk Processed # / day	#BOD/ 1000# Milk Proc.	#Waste Water /# Milk Proc.	Level Management Practices	Explanation of Prac.
1	Milk	400,000	0.3	0.4	Excellent	Rinses saved, hoses off - out of use, Filler drip pans
42	Milk	150,000	7.8	5.2	Poor	No steps taken to reduce waste
43	Milk		0.2	0.1	Excellent	Rinses saved, returns excld Filler drip pans cooling power
6	Cottage Cheese	600,000	2.0	0.8	Good	Whey excld, Fines screened out, Wash water to drain
36	Cottage Cheese	300,000	1.3	4.7	Good	Whey excld, Spilled curd handled as solid waste
37	Cottage Cheese	650,000	71	12.4	Poor	Whey incld, poor housekeeping Rinses to drain leaks, drips
9	Ice Cream	17,000	32.2	5.3	Poor	Water running-not in use
26	Ice Cream	34,000	2.1	0.8	Good	Freezer rinses segregated
48	Milk Cottage Cheese	250,000	0.7	1.0	Good	Whey & wash water excld Rinses segregated
8	Milk Cottage Cheese	1,000,000	8.6	7.0	Poor	Whey excld, many drips leaks, returns incld
10	Milk	900,000	3.3	1.1	Fair	Whey excld. Good water volume control
40	Milk Cottage Cheese	1,000,000	2.1	1.2	Good	Whey excld, rinses saved

Table 7. (Cont.'d)

Plant No.	Products Manufactured	Milk Processed # / day	#BOD/ 1000# Milk Proc.	#Waste Water /# Milk Proc.	Level of Management Practices	Explanation of Prac.
52	Milk Cottage Cheese	765,000	1.8	1.1	Good	Returns excld, good water control
3	Milk Ice Cream Cottage Cheese	400,000	3.9	1.4	Fair	Whey & wash water excld Rinses excld
30	Milk Ice Cream Cottage Cheese	800,000	7.7	3.5	Poor to Fair	Whey excld, sloppy oper spillage, leaks, hoses run
33	Milk Ice Cream Cottage Cheese	600,000	12.9	3.3	Poor	Whey incld, poor housekeeping pumps, valves, lines leak hoses run
34	Milk Ice Cream Cottage Cheese	900,000	9.1	2.8	Poor	Whey excld, many leaks, drips, etc.
44	Milk butter	300,000	0.9	0.8	Good	Buttermilk excld, few leaks, dry floor cond.
50	Whey Powder	500,000	0.2	5.9	Good to Fair	No entrainment losses, all powder handled as solid waste, no leaks or drips
56	Milk Powder Butter	200,000	3.0	2.5	Fair	Continuous churn hoses running, numerous leaks & drips

clearly revealed that there was a direct relationship bewween management attitudes and practices and the coefficients. Under extremely good management, coefficients of 0.5 pounds of waste water per pound of milk processed and 0.5 pounds of BOD per thousand pounds of milk processed were obtainable. A realistic average of 2.0 pounds of BOD per thousand pounds of milk processed and 1.5 pounds of waste water per pound of milk processed appeared to be generally achievable under good management. Coefficients above 3.0 can be considered to be excessive and an indication of poor management.

With whey and water milk excluded, the waste coefficients of different operations are quite similar. If the overall average coefficients of 2.4 for volume and 5.8 for BOD are assumed to be representative of the national dairy food industry, the total waste water from dairy food plant operations would be equivalent to 200 million pounds of waste water with 475 million pounds of BOD_5 per year. Since observations have indicated that plants without prior knowledge of their waste loads have coefficients in excess of three pounds of waste water per pound of product processed and 3.0 pounds of BOD per thousand pounds of product processed, the actual amount of BOD from dairy food plants - taking into consideration the 50 percent wasting of by-products at the present time, we can estimate a current overall organic waste load from dairy food of 4.0 billion pounds of BOD_5 per year at the present time.

BOD-COD Inter-relationships

The 195? Revised Guide for Dairy Plant Waste Treatment (19) recommended the utilization of COD in preference to BOD_5 as a means of measuring the strength of the wastes. This recommendation was based on the work of Porges and co-workers(11) utilizing skimmilk as a model for dairy food plant wastes. Investigators are in agreement in respect to the BOD-COD relationships between whole milk, skimmilk and whey. The average values cited are:

Product	BOD-COD ratio
Whole milk	0.69
Skimmilk	0.63
Buttermilk (churned)	0.66
Whey	0.52
Lactose	0.53
Casein	0.46
Whey protein	0.23
Fat	1.28

With the exception of the BOD-COD ratios of the constituents of milk are much lower and the lowest biologically oxidizable material is the whey protein.

BOB-COD ratios reported in the literature for industrial dairy food plant wastes are shown in Table 8. Values vary widely and are generally less than for milk products themselves, as might be anticipated. Overall, the BOD-COD ratio ranged from 0.10 to 0.88 with an average of 0.53, as compared to a BOD-COD ratio of 0.65 for whole milk. Values below 0.6

Table 8. BOD_5/COD Ratios for Raw Dairy Plant Wastes

Investigator	Type of Plant	Year	BOD_5/COD ratios Range	BOD_5/COD ratios Average
Hoover & Porges	-	1953	0.34-0.80	-
Schulz-Fulkenheum	-	1955	0.30-0.70	-
Walholz	-	1956	-	0.64
Furoff	multi-produce	1960	0.22-0.51	0.33
Schweizer	cheese	1960	0.31-0.66	0.45
Rensink	butter	1962	-	0.66
Christansen	-	1964	0.55-0.77	0.64
Walgren	-	1966	0.11-0.75	0.47
Bergman, et al	multi-product	1966	0.43-0.60	0.53
Bergman, et al	multi-product	1968	0.40-0.75	0.56
Annon	-	1968	0.22-0.88	0.35
Current plant survey	-		0.10-0.76	0.48
Total			0.10-0.88	0.53

can be interpreted to suggest less efficient biological oxidation of milk westes than pure milk; probably caused by the presence of non-milk constituents. Possible "toxicity" of dairy plant waste is suggested by values below 0.4, but no reference to possible "toxicity" has been previously cited.

In the course of this investigation, several national and/or regional dairy companies who have had a long experience in measuring the strength of dairy plant wastes, indicated they had attempted to utilize COD but abandoned the position several years ago because of wide variations in BOD-COD ratios and apparent lack of agreement between values suggesting that COD values were less reproducible and of less value than BOD. Data was obtained from one plant for BOD-COD ratios in raw and treated wastes at hourly intervals during a production day. As shown in Table 9, the ratios varied from 0.12 to 0.90 at different periods of the day. Low ratios between 1:00 and 5:00 p.m. coincided with the major periods of equipment process cleaning. These low values suggest either "toxicity" from detergents or the presence of a large amount of refractory material.

Solids, pH and Temperature

Available information from industry for solids, pH and temperature of dairy food plant waste water in relation to BOD strength is summarized in Table 10. The suspended solids content of dairy plant waste waters from the literature varied between 2400 and 4500 ppm. Based on the limited literature values available, there was no statistically significant correlation between the suspended solid strength and the type of dairy plant operation. The data suggest that over 70 percent of the suspended

Table 10. Solids, pH and Temperature of Dairy Food Plant Waste Waters (Industry Values)

Waste Component	No. of Values	Range	Average
Suspended Solids, ppm	24	24-5700	-
Volatile Suspended Solids, ppm	19	17-5260	-
Volatile Total Solids, ppm	22	57-4700	1497
Total Solids, ppm	27	135-8500	2397
pH	30	5.3-9.4	7.1
Temperature,°F	17	55-120	76
BOD, ppm	11	15-4790	2100

Table 9. BOD/COD Relationships in Raw and Treated Dairy Plant Wastes (1967) at Hourly Intervals*

Time	BOD:COD Ratios Raw	BOD:COD Ratios Treated	Rate of Waste Water Flow (mgd)	Raw COD Values
8:00 a.m.	.4	.32	.025	3440
9:00 a.m.	.35	.29	.020	3200
10:00 a.m.	.51	.26	.025	3400
11:00 a.m.	.28	.25	.010	4700
12:00	.66	.15	.035	2600
1:00 p.m.	.26	.48	.035	3400
2:00 p.m.	.21	.90	.035	5200
3:00 p.m.	.21	.82	.050	5800
4:00 p.m.	.12	.77	.035	9280
5:00 p.m.	.25	.59	.045	6240
6:00 p.m.	.45	.75	.035	7760
7:00 p.m.	.60	.57	.014	3200
8:00 p.m.	.57	.68	.020	4480
9:00 p.m.	.55	.54	.020	2720
10:00 p.m.	.88	.64	.022	2400
11:00 p.m.	.90	.63	.010	1056
12:00	.90	.60	.005	886

*Equipment Sanitized 6 - 8 a.m.
Clean up 1 - 6 p.m., maximum activity about 2 - 4 p.m.

solid is volatile, or organic in nature, in dairy food plant waste waters. Volatile suspended solids, as percentage of total suspended solids, ranged from 68 percent to 98 percent with an average of 85 percent. The suspended solids are composed primarily of coagulated milk, fine particles of cheese curd and pieces of fruits and nuts from ice cream operation, and contribute from 10 percent to 30 percent of the total solids. Volatile solids as percentage of total solids, ranged from 36 percent to 96 percent with an average of 63 percent. The non-organic total solids is about twice the non-organic volatile suspended solids. The proportion of non-organic solids in milk is about 13 percent, which suggests that most of the suspended solids in dairy food plant waste waters are of a dairy food origin. The increase of non-organic matter in a total solid reflects the contribution of non-organic material from detergents, sanitizers and lubricants.

The pH of the dairy food plant waste waters varied from 4.4 to 9.2 with a median value of 7.2. Although it would be expected that cheese plants might have a lower pH in their waste water than other types of plants, this was not found in the data available. The major factor affecting pH of dairy food plant wastes is the cleaning compound, either acid or alkali and its relative significance in the dairy food plant waste water.

Suspended solids to BOD ratios ranged from 0.25 to 0.35 with an average of 0.31, and the total solids to BOD ratios were essentially identical for different types of dairy plant wastes with an average of 1.62. The relationship of solids to BOD appeared to be independent of the type of dairy plant operation and characteristic of all dairy plant waste waters.

Only limited studies have been made of the temperature of dairy food plant waste waters as they leave the dairy plant. Reported values ranged from 70°F to 115°F (20°C to 40°C). The most comprehensive study in this area was made by Zall(24) who showed that waste water temperature in a small dairy plant could be reduced about 15 percent by management control of the use of hot water in cleaning, and by eliminating the practice of allowing hot water hoses to run while not in actual use.

Chemical Composition of Dairy Food Plant Waste Waters

No systematic complete study of the chemical composition of dairy plant waste waters has been made to date, and only limited data is available. The most comprehensive studies have been those of Walgren(20) and Sårkk(13), for dairy plants in Sweden and Finland, respectively. Compositional data for the major organic constituents in dairy food plant wastes are essential to a better understanding of the consistency of the composition of dairy wastes and the oxygen reqirements of these waste waters for treatment, since the oxygen consumed varies from compound to compound. Information on mineral constituents of dairy food plant wastes is important because of the role of the various refractory elements in water quality. The organic composition and concentration of phosphate and chloride reported in various studies are presented in Table 11 for literature and industrial survey data. Limited data indicate the following differences in the ratios of fat to protein and to lactose.

Source	Protein/Lactose Ratio	Fat/Lactose Ratio
whole milk	0.64	0.70
dairy waste water	0.56	0.12
dairy waste water	0.43	--
dairy waste water	0.85	0.57
dairy waste water	1.08	0.42
dairy waste water	1.14	--
dairy waste water	0.32	0.05

Protein/lactose ratios and fat/lactose ratios in dairy food plant wastes are significantly different from those for whole milk.

The phosphate values which vary independently of BOD, were all in excess of 10 ppm and could be considered as a potential source of phosphate for inhancing algae growth. The values varied widely, apparently reflecting a difference in the amount of phosphate cleaning compound used in different dairy operations. Most chloride values in waste water exceeded 75 ppm which is considered to be the level that cannot interfere with industrial processes. Forty-five percent of the chloride values given exceeded 250 ppm.

To interpret the data of these and other refractory elements in dairy wastes; values for calcium, potassium, sodium, phosphorous, magnesium, chloride and nitrogen in milk wastes containing 0.1 percent (1000 ppm BOD_5) milk solids would be:

Material	ppm
BOD	1000
nitrogen	55
chloride	10
phosphorous	12
calcium	12
sodium	4
potassium	15
magnesium	5

Available data for magnesium, calcium, sodium and potassium are also summarized in Table 11. The values differ widely in respect to sodium (60-807 ppm), and potassium (11-160 ppm) and were less variable for magnesium (25-49 ppm), and calcium (57-112 ppm). Variations in the latter two minerals reflected variations in BOD, whereas variance in

Table 11. Chemical Composition of Dairy Food Plant Waste Water

Constituent	PPM Range	PPM Average
BOD	450-4790	1885
Nitrogen	15-180	76
Protein	210-560	350
Fat	35-500	209
Carbohydrate	252-931	522
P	11-160	50
Cl	48-469	276
Ca	57-112	37
Mg	25-49	87
N	60-807	322
K	11-160	67

sodium and potassium were unrelated to BOD and reflected differences in the sodium and potassium composition of cleaning compounds and water treatment utilized in the different plants. Based on these data, milk salts would contribute about 10 to 50 percent, 10 to 75 percent, 1 to 10 percent, and 25 to 100 percent of the magnesium, calcium, sodium and potassium ions, respectively in dairy food plant wastes. Thus, 90 percent of the sodium, 50 percent of the magnesium and 25 percent of the calcium appeared to come from non-dairy sources, presumably cleaning compounds, detergents and lubricants.

Lubricants are not mentioned in the literature as a source of pollutant in dairy plant waste waters, only limited data could be obtained during the course of this study concerning specific contribution of these materials to BOD. Most of the lubricants are salts of fatty acids and range in BOD from 0.8 to 1.2 pounds of BOD_5 per pound of material.

Detergents and Sanitizers

Selected compounds used in the manufacture of detergents and related materials and their contribution to BOD_5 (lb/lb of product) are shown in Table 12. Wetting agents and surfactants varied widely in BOD values ranging from 0.05 to 1.2. The most commonly utilized surfactant contained 0.65 pounds of BOD_5/ pound of product; non-ionic wetting agents exhibit a low BOD, with average values of 0.2 pounds BOD per pound; and acids which are used in dairy food plant detergents, have BOD values ranging from 0.25 to 0.85. The most commonly used acid detergent in cleaning food plant equipment has a BOD value of 0.65 pounds BOD_5/pound of detergent.

Table 12. BOD_5 of Selected Chemicals in Detergents, Sanitizers, and Lubricants used in Dairy Food Plants

Material	#BOD/# Product
Acetic acid	0.65
Duponol D, alkyl alcohol, sufonated	0.45
70% hydroxyacetic acid	0.07
alkyl phenyl condensate of ethylene oxide	0.04
Phenoxypolyloxyethylene	0.005
Nacconol NR-Na alkylarylsulfonate	0.004
Neutrony x 600, aromatic polyglycol ether	0.0
Nopco 1111-sulfonated coconut oil	0.96
Nopco 1665-soluble fatty acid ester	0.12
Pine oil	1.08
Tallow	1.52
Triethanolamine	0.01
Ultra Wet DS-soldium alkylarylsulfonate	0.0
Linear alkylarylsulfonate	0.65
Ethylene glycol	0.70
Zalon-fatty amide	0.20

The amount of various detergent components used in cleaning various types of dairy food plant by hand and CIP method were calculated and are listed in Table 13 in lb/1000 lb of milk processed. Alkali, as sodium hydroxide, is the major component ranging from 0.23 to 1.52 lb/1000 lb of milk processed for hand cleaning and from 0.23 to 0.47 for CIP. Phosphate values ranged from 0.05 to 0.76 and 0.04 to 0.21 for CIP and hand cleaning, respectively. Acid ranged from 0.08 to 0.84 for hand cleaning and from 0.07 to 0.15 for CIP, whereas surfactant was the component used in the lowest concentrations, with amounts per thousand pounds of milk processed ranging from 0.02 to 0.11 for both hand and CIP cleaning, respectively. Ice cream plants utilized the highest concentration of detergents, with the least differences between hand and CIP cleaning procedures. This reflects the relative amount of equipment in ice cream plants still cleaned by hand and the fact that CIP is limited to pipelines and storage tanks.

Only acids and surfactants contribute BOD to the waste water. The amount of BOD_5 in the waste water in lb/1000 lb processed from materials used in dairy food plant detergents as a function of concentration is shown in Figure 1. Under average conditions in the modern milk plant, the amount of BOD contributed by surfactant and acid detergent could be about 0.1 lb/1000 lb of milk processed. The organic acid appears to be the major source of BOD and could be substituted by an inorganic acid. However, the major inorganic acid of choice will be phosphoric acid which would add substantially to phosphate levels.

Table 13. Coefficients of Components of Cleaners & Sanitizers #/1000# Milk Processes

Product	Market Milk		Butter		Cheese		Condensed & Powder		Ice Cream	
	hand	CIP	hand	CIP	hand	CIP	hand	CIP	hand	CIP
Alkali (NaOH)	0.77	0.25	0.79	0.25	0.65	0.41	0.23	0.21	1.52	0.47
Phosphate (hexa-meta PO4)	0.12	0.05	0.76	0.15	0.38	0.07	0.046	0.04	0.22	0.22
Surfactant	0.08	0.02	0.025	0.08	0.08	0.05	0.02	0.02	0.11	0.11
Acid	0.84	0.15	0.35	0.10	0.14	0.09	0.088	0.07	0.52	0.15
Chlorine	0.34	0.10	0.14	0.08	0.08	0.03	-----	----	0.37	0.13

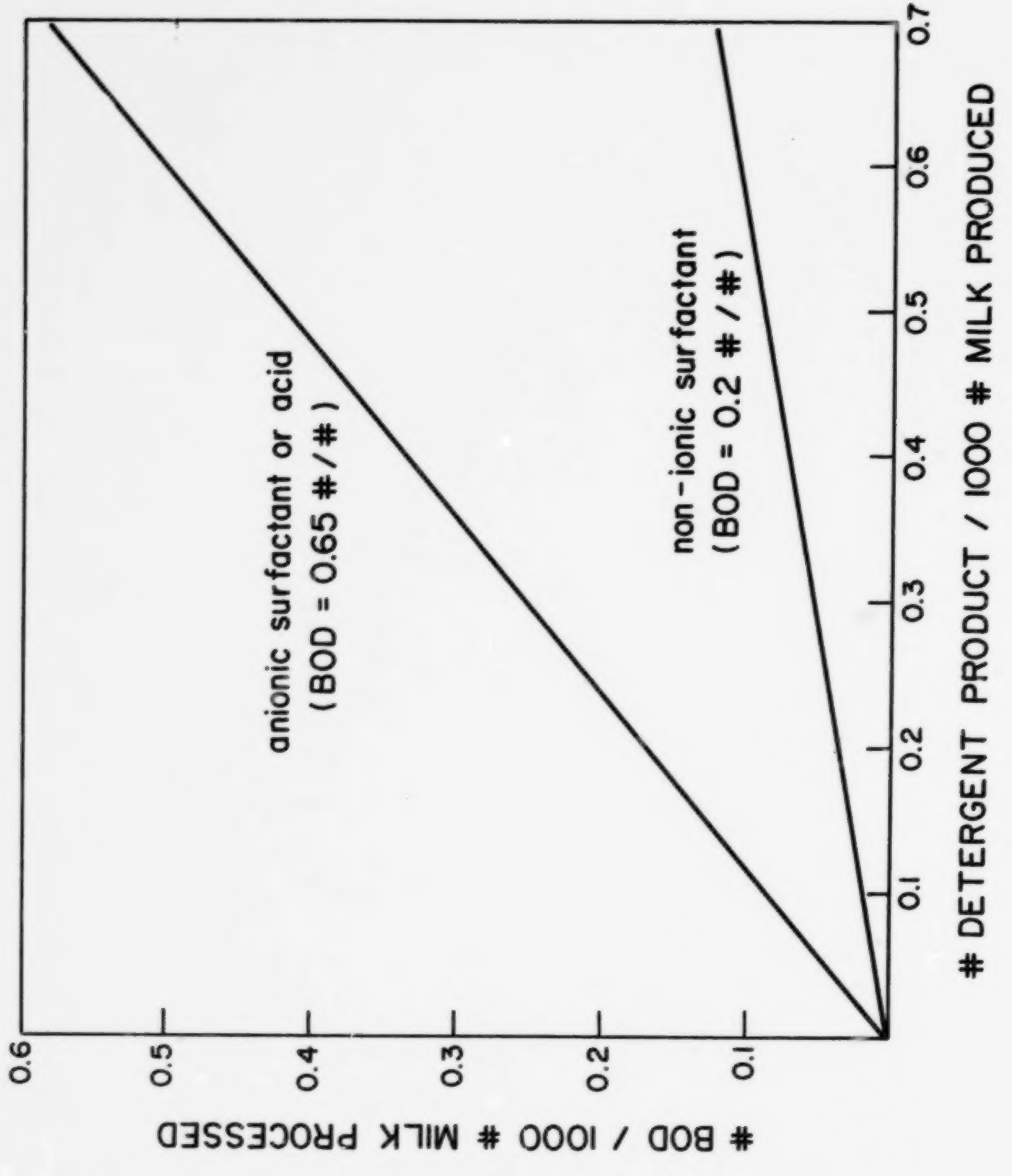


Figure 1. Contribution of Detergent Materials to BOD in Dairy Plant Wastes

Data for cleaning and sanitizing solution in dairy plant waste water for 27 plants are summarized in Table 14. Cleaning solution in percent of waste water, ranged from 2.2 to 41.6 percent with an average value of 15 percent. The sanitizer solution contributed 0.2 to 13.8 percent of the waste water and averaged 3.1 percent. The lower the waste water coefficient for a dairy plant, the greater was the percentage of that waste water made up of detergent and sanitizer solutions. The average concentration of the detergent in the cleaning solution would be 5000 ppm and for sanitizers the average would be 100 ppm. In terms of the waste water, the concentration of alkali, sodium hydroxide, ranged from 32 to 6280 ppm with an average of 500 ppm; phosphate ranged from 30 to 75 ppm with an average of 43 ppm; acid ranged from 10 to 348 ppm and averaged 66 ppm; whereas chlorine ranged from 6 to 234 ppm and averaged 70 ppm.

Based on the data obtained during this investigation, it will appear that detergents and sanitizers may be more significant in dairy wastes than previously reported(4). They potentially contribute significantly to BOD, to refractory COD and may be significant in providing toxicity and poor performance to dairy waste treatment facilities. Their effect on the dominating microflora of dairy food plant waste treatment systems and a full determination of their real significance requires further investigation.

Variation in Dairy Food Plant Wastes

Frequency plots of the variability in day to day BOD_5 values for six different dairy plants are shown in Figure 2. Five of the six plots follow a normal distribution and show a straight-line relationship, whereas the sixth plot shows an S-shaped distribution typical of very poor day to day control. Where normal distribution existed, the maximum BOD level (at a 1 percent confidence limit) ranged from 1.77 to 2.46 times the mean value, with an average of 2.1. For the plant with abnormal distribution, the maximum BOD was 3.6 times the mean value.

Variation is a characteristic of dairy food plant wastes which needs to be evaluated on a plant to plant basis in order to provide information for both design and proper operation of waste treatment systems. On a daily basis, control of variables in the proper process can result in a normal and predictable distribution around the mean. Generally, maximum values at 1 percent confidence limit can be predicted by multiplying the mean value by 2.5.

Sources of Dairy Food Plant Wastes

The most visible pollutant in dairy food plant waste waters is whey from cheese and cottage cheese operations; with about 17 billion pounds of sweet whey being produced annually in this country from ripened cheese and about 6 billion pounds of acid whey coming from cottage cheese and allied processes. The next most significant source of BOD_5 is derived from every 1000 pounds of milk processed into cottage cheese from whey and another 8 pounds comes from the wash

Table 14. Cleaning and Sanitizing Compounds in Dairy Food Plant Waste Water

	% Waste Water as				Average ppm of Following				
	Cleaning Solut.		Sanitizing Solut.						
Type of Plants	Range	Aver.	Range	Aver.	Alkali	Acid	Phos-phate	Sur-factant	Cl
Milk	3.4-21	9.4	0.6-5.0	2.2	353	51	175	52	155
Cheese	4.6-22	14.3	5.0-6.2	5.8	---	--	---	--	52
Ice Cream	2.22	12.0	0.2-3.0	1.3	43	33	10	5	16.8
Cottage Cheese	---	18.0	---	10	150	75	64	21	234
Milk & Cottage Cheese	7-41	17.0	0.3-13.8	3.4	360	55	56	41	102
Milk, Cottage Cheese and Ice Cream	10-22	15.6	1.4-5.0	3.0	184	34	73	25	57

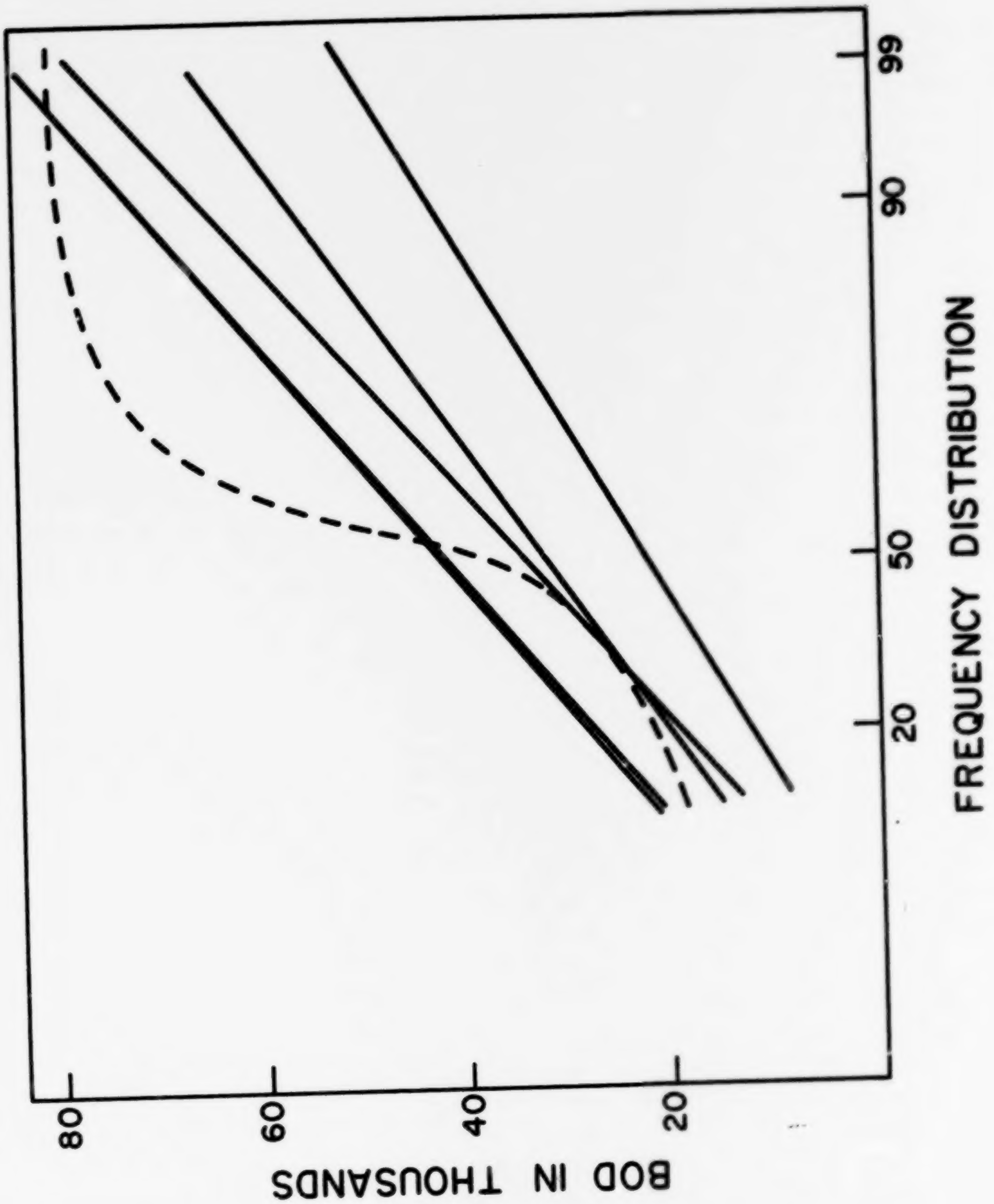


Figure 2. Day to Day Variations in BOD in the Wastewater of Different Dairy Food Plants

water. Under average conditions the total BOD_5 from all other dairy food plant processes combined is about 2-5 lb/1000 lb of milk processed. Literature values, for BOD_5 from various unit operations which are in general agreement with each other, have been presented by two investigations(2, 18). Values obtained from several modern, automated dairy food plants manufacturing fluid milk product and cottage cheese are in Table 15. Exclusive of whey and wash water, the process yielding the highest BOD_5/1000 lb of milk processed is pasteurization; with the milk solids coming from the start-up, change-over and shut-down of the process on water. The next most significant source is the filling operation, where machine jams in high speed packaging equipment is frequent. The loss of 5 to 10 gallons of milk in a single machine jam is not uncommon.

Limited data for ice cream operations indicated that the loss of BOD_5 in rinsing mix tanks and ice cream freezers ranged from 2-10 lb of BOD_5/1000 lb of milk processed into ice cream. Because of the high viscosity of the mix and ice cream, the percentage of product remaining on the surface after draining can be up to 8.5 percent of the total present in the processing equipment.

Because of its significance, as indicated in other presentations today, the cottage cheese operation merits special attention. Cottage cheese whey BOD_5 values in industrial practice were found to range from 30,000 ppm for filtered whey to 65,000 ppm for whey with a high level of fine particles present. Thus, in addition to whey and wash water, the amount of curd shattering can be a significant source of both BOD and suspended solids in cottage cheese operations. The BOD_5 for whey, wash water and fines in one commercial dairy food plant is presented in Table 16. As indicated, the total BOD value of the fines was lb/1000 lb of milk processed into cottage cheese. The first wash water contained about 60 percent of the total BOD in the wash waters. Effort is needed to minimize the BOD in wash waters, since the solids level (less than 2.0 percent) is too low for practical recovery. This may be accomplished by: (a) complete draining of the curd, followed by addition of 10 percent volume of wash water that is drained and combined with the whey, before the first complete washing, (b) utilization of whey as a means of cooling the curd, in which whey is removed, cooled and pumped back on the curd; thus reducing the volume of wash water required, and (c) counter current washing through a cooling tower. The possibility exists also for developing new methods of cottage cheese manufacture from concentrated milk which would reduce the volume of whey and wash water, but this is in the future from a practical viewpoint.

Waste Control and Treatment

Waste Reduction:

Minimization of waste water volume and strength is necessary to reduce the waste coefficients found in most plants to the achievable level of about 0.5 pounds waste water/lb of milk process and 0.5 pounds of BOD_5/1000 lb of milk processed. This can be achieved with current technology, if management makes the necessary effort.

Table 15. Industrial Data for BOD Coefficients for Unit Processes in Two Fluid Milk Cottage Cheese Plants

Process	lbs of BOD/1000 lbs of milk received Plant A	Plant B
Tank truck rinsings	0.25	--
Silo tank rinsings	0.23	--
Tank trucks and storage tank rinsings	--	0.25
Separation (CIP)	0.15	--
CIP Separator sludge	--	0.08
HTST Start up and Change over and cleaning	0.75	0.55*
Filling operations-milk	0.30	0.32
Lubricants	--	0.08
Product Returns	--	0.10
Cottage cheese wash water	0.33	0.60
Unaccounted	0.20	0.03
Total Waste Water	2.16	2.01

*Initial start up collected, product change overs not diverted.

Table 16. BOD Coefficients for Cottage Cheese Operations*

Operation	ppm BOD		#BOD/1000 lb. milk proc.	
	A	B	A	B
Whey C. C.	3,700	3,500	26.6	25.2
First wash	17,000	11,700	5.8	6.3
Second wash	1,700	2,200	1.3	1.2
Third wash	2,000	550	0.7	0.30
Fourth wash	2,200	--	0.75	--
Transfering & Filling+	--	185,000	--	0.027
Fines	--	--	--	2.2

*Operation A used 3 washing with each wash being equal to 75 percent of whey volume. Operation B used 5 washes, with the 1st, 3rd, and 4th washes being equal to 50 percent of the whey volume and the 2nd wash being equal to the whey volume.

+Values based on curd spillage. Usual amount of curd loss would range from 5-10 lb/100 lb of cottage cheese.

To optimize the control of waste in the dairy industry, the following suggestions are made for plant operations.

1. Segregation of all major sources of waste with separated drains as required being put into all new plants and remodeled plants.
2. Segregation of recycling of non-polluted water (including water, etc.).
3. Utilization of the automation system of the plant to eliminate wates; collecting the first rinses from tanks and cleaning operations, and saving the water-milk mixtures resulting from start-up and changeover shutdown of HTST units.
4. Eliminating all product discharged during start-up from product changeover of HTST pasteurizers.
5. Improvement in the efficiency of CIP and sanitizing operations to reduce required concentration on these materials.
6. Use of post-cleaning rinses as make-up water for sanitizing and/or cleaning.
7. Elimination of returns from waste water streams.
8. Collection of lubricants and reclamation for reuse.

Implementation of these practices can reduce BOD_5 coefficients to about 1.0 pound in a well managed plant.

Waste Treatment

Dairy food plant wastes are treated primarily by biological oxidation methods, with over 90 percent of all the dairy food waste water being treated in municipal systems. Where the municipal systems are receiving more than 50 percent of their BOD_5 from milk wastes or more than 10 percent of the BOD_5 from whey, the treatment plant takes on characteristics of a dairy food plant waste treatment system.

Biological oxidation is a function of the microflora of the waste treatment system, which in turn is dependent upon the composition of the wastes. According to Dias and Bhat(3), the dominant microflora in a municipal activated sludge plant in decreasing order are Zoogloea, Comannanmonas, Pseudomonas, Micrococcus, Flavobacterium , Achromobacter, Alcaligenes, Corynebacterium, Bacillus, Spirillum and yeasts. All of these have been found in activated sludge of dairy waste treatment. However, the dominant microflora reported by various investigators for dairy activated sludge are quite different from that of domestic activated sludge. Adamse(1) found that the adaptation of the bacterial flora from municipal to dairy wastes required approximately 50 to 60 days.

In his investigations, the dominant microflora were Corynebacterium, of the Arthrobacter type, followed by Achromobacter. Pipes(10) in his investigations of activated sludge plants found that the dominant microflora in his particular investigations were Bacillus, Beggiatoa, Arthrobacter, Actinomycetales, and Sphaerotilus. Similar microorganisms have been reported in the microflora from trickling filter and aerated lagoon systems operating on dairy wastes.

Only limited investigations have been made of the metabolisms of the microflora of various dairy food plant waste treatment systems. Since the dominant microflora of dairy food plant waste treatment systems appear to differ from the microflora of municipal systems, there is need for further specific information. The most exhaustive study in respect to the factors affecting the metabolism of the microflora of dairy food plant waste treatment systems have been conducted by Adamse(1). In investigation of the growth characteristics of the major groups of organisms in his system, he found that the Arthrobacter species was the most active and efficient of the three types, with a generation time of 2.5 hours at 15°C. In batch experiments with well aerated activated sludge, the oxygen demand immediately after feeding artificial dairy wastes was found to exceed the oxygen supply. This caused a decrease in dissolved oxygen content of the material and a simultaneous increase in the COD of the effluent. During the dissimulation of the substrate, acid intermediates from carbohydrate breakdown were excreted to the system, with sharp drop in pH. This suggested that the oxidation of the carbohydrate fraction was limited even though adequate amounts of oxygen were supplied. The decrease in the pH preceded more slowly when the dissolved oxygen content approached 0, indicating that acid formation was due to activity of aerobic organisms. From the results obtained, the conclusion was reached that the dissimulation period for protein fraction proceded at a remarkably lower rate than dissimulation of carbohydrate fashion. Typical data are presented in Figure 3. In studying the metabolism of sludge microorganisms, Adamse found that the drop in pH in the activated sludge shortly after feeding was due to the accumulation of acetic acid in the presence of adequate dissolved oxygen, and lactic acid accumulated when dissolved oxygen was below 0.5 ppm. Both acids were degraded after lactose had been exhausted, but lactic acid was more readily oxidized than acetic acid. The apparent degradation rate of dairy wastes was found optimal at pH 6.5 of the activated sludge suspension. Of the lactose added to the activated sludge, approximately 10 percent was respired, up to 50 percent was accumulated in polysaccharides in the cell biomass and the remainder was used for the synthesis of cell constitutent and partly accumulated as intermediates in the sludge mass.

The difficulty in the treatment of whey appears to be related to the inability of microorganisms to degrade whey protein and the ability of these proteins to interact with the polysaccharide of the cell mass.

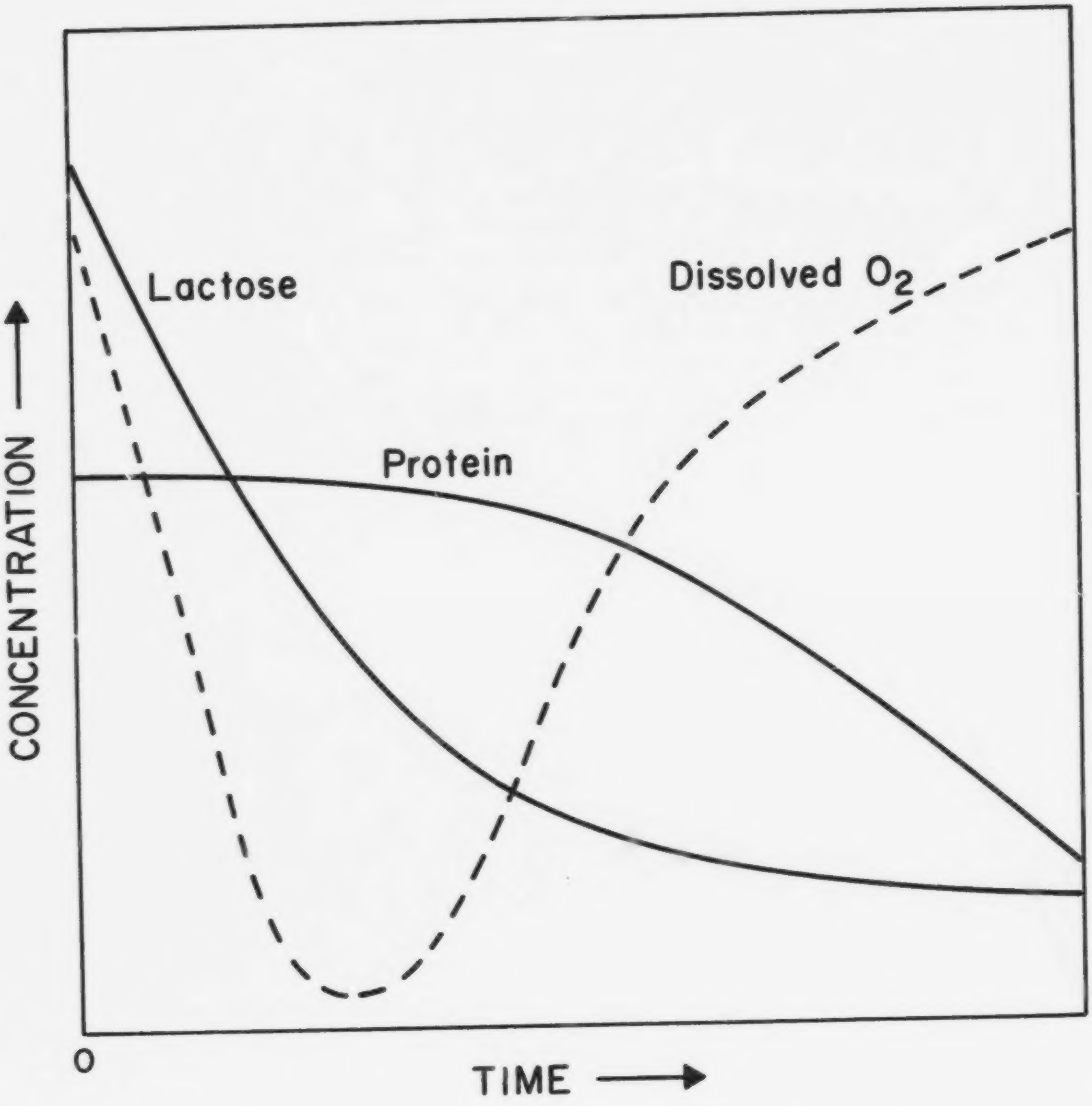


Figure 3. Diagramatric Representation of Changes in Dairy Wastewater During Treatment of Activated Sludge

Incorporation of whey or whey wash water in the activated sludge treatment plants have been known to cause excessive foaming. The foam has been shown by our earlier studies to be a combination of microbial cells and major whey protein B-lactoglobulin. Although the BOD/N ratio of milk wastes approximate those desired (20:1), the available nitrogen is considerably less because of the binding of the protein to the cell mass and the inability of enzymes to readily degrade material. Ammonium nitrogen has been frequently indicated as a requirement in dairy food plant waste waters. However, many dairy food plant waste treatment systems and some investigators have failed to show an increased efficiency in BOD reduction through the addition of nitrogen; and the exact reason for these observations needs further investigation.

Waste Treatment Methods

The types of biological waste treatment methods utilized in the dairy food industry are primarily activated sludge, trickling filters, aerated lagoons, irrigation and a combination of these.

Characteristics with respect to loading and efficiency of BOD reduction are summarized for selected treatment systems in Table 17. The data are not inclusive of those collected, but illustrate the differences that have been reported. Text books and many authors repeatedly state that dairy food plant wastes are easier to treat than municipal wastes. By this, most mean that because of the relatively low suspended solids, it is not necessary to go through an extensive solids removal prior to biological oxidation. However, in practice, it has been shown that the biological oxidation phase of waste treatment is much more difficult than for municipal waste systems, primarily because of the high organic load and because of the variability in both hydraulic and organic loading. Efficiencies of biological oxidation treatment systems for dairy wastes are generally reported to be higher than 90 percent. In the site visits and from those studies that have been exhaustively reported in the literature, it becomes apparent that this degree of efficiency is achieved only for a part of the operating time. Based on some twenty evaluations of treatment plants for dairy wastes, it was found that the waste treatment facilities were less than 70 percent efficient about 25 percent of the time. Figure 4 shows typical frequency plots of the variability of waste treatment for several systems treating only dairy wastes.

Because of the high BOD load, and in many modern plants up to 4000 ppm, even 99 percent efficiency does not bring the BOD in the effluent down to a level acceptable in some states for direct discharge to a stream. As a result, an increasing number of plants that have their own treatment facilities are combining two or more biological treatment methods. It would appear that a two-stage or three-stage biological oxidation is necessary in order to provide for optimum treatment to meet stream standards.

Table 17. Comparison of Waste Treatment Methods for Dairy Food Plant

Method of Treatment	BOD$_5$ in ppm				% Reduction In BOD$_5$		Loading		Retention Time (hrs)	
	Untreated		Treated							
	Range	Aver.	Range	Aver.	Range	Aver.	Range	Aver.	Range	Aver.
Activated Sludge (10)	84-2,920	404	7-632	85	17-99	79.08	0.018-1.10	0.35[a]	----	----
Activated Sludge	180-15,000	1903	1-1700	163	57-99.8	88.7	0.06--485	137[b]	1.5-120	21.4
Trickling Filter	130-32,000	2846	10-1400	81	35-99.5	77.4	0.4--49.4	12.7[c]	No information avail, estimate 36-48 hrs.	
Aerate Lagoons	75-10,000	286	25-800	191	52-89.5	76	10-395	162[d]	168-1080	420 (17 days)
Irrigation[e]	-	220	-		-		2500-90,000	27,700[f]	-	-

[a] lb BOD/lb MLSS; [b] lb BOD/100 cubic feet; [c] lb BOD/cubic yard; [d] lb BOD/day/acre; [e] BOD loading generally not given, the value of 220 is given as maximum loading rate recommended; [f] volumetric loading in gallons/day.

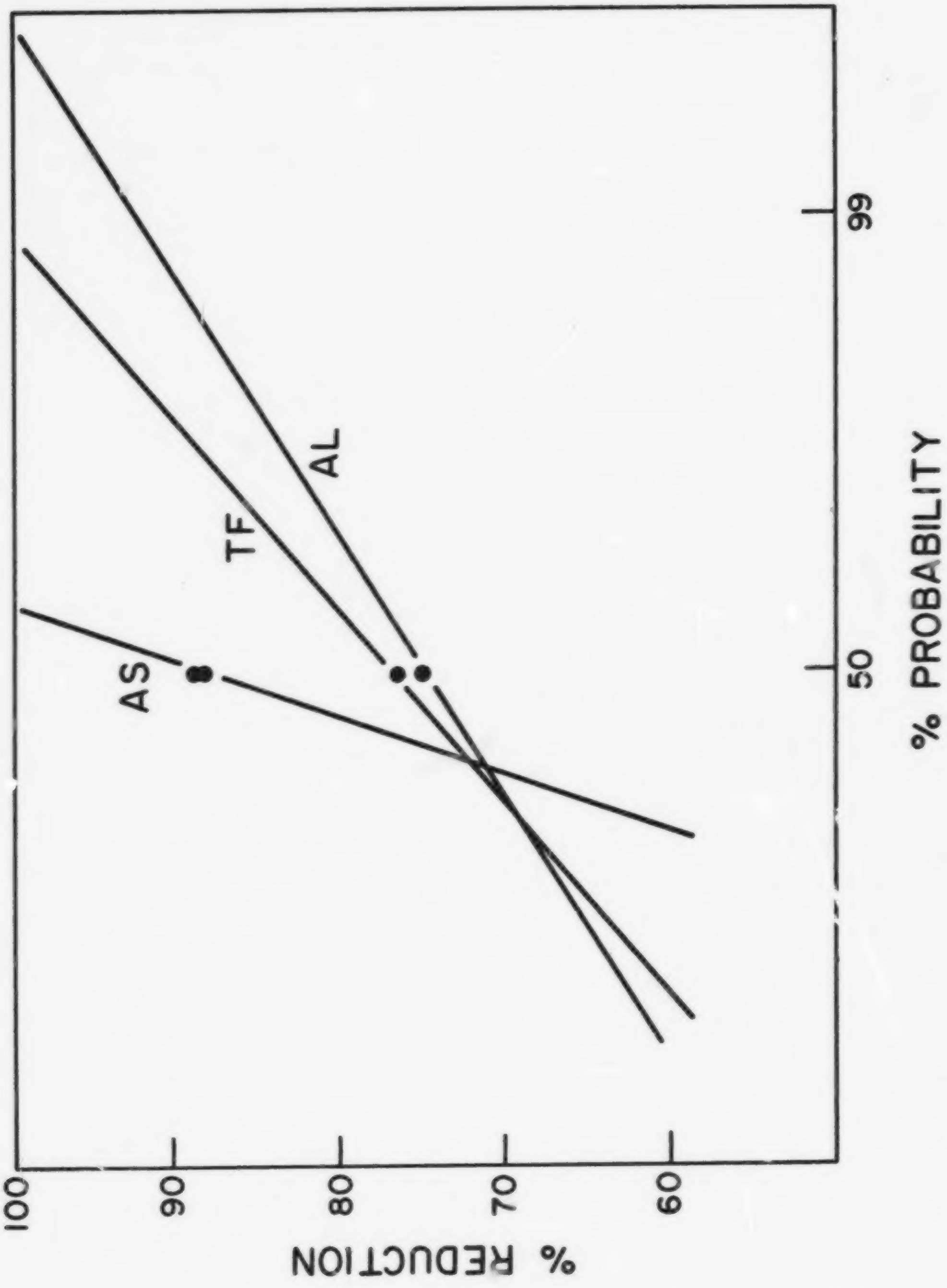


Figure 4. Variation in the Efficiency of Different Types of Waste Treatment for Dairy Waste (AL = Aerated Lagoon; AS = Activated Sludge; TF = Trickling Filter)

The relative efficiency for BOD and COD treatment under commercial dairy plant operations obtained from plants surveyed in this study are presented in Table 18. Values show that in one dairy food plant waste in which the BOD of the effluent was 15 ppm, the COD of the effluent was 175 ppm. This may reflect the refractory nature of certain detergents and chemicals used in the cleaning and sanitizing of dairy food plant equipment.

Problems encountered in the treatment of dairy food plant wastes include:

1. Periodic poor performance, and lack of correlation between loading rate, sludge characteristics and BOD reduction.

2. Poor settling characteristics of sludge in activated sludge systems, with problems of pin point floc, deflocculation and bulking.

3. Periodic loss of the biomass in trickling filter systems.

4. Low levels of available nutrients, caused by possible complexing of milk constituents with microbial cells, and possible feed back inhibition of B-galactosidase by lactic acid.

5. Slow recovery of the biological activity of the treatment systems, after shock loading, or periods of low feeding.

6. High organic concentrations, high hydraulic and nutrient variability and consequent shifts in the microflora of the waste treatment facility.

7. Possible "toxicity" in some dairy wastes, attributable to sanitizers and detergents.

8. Stable, high strength foams in activated sludge systems in the presence of whey or often cottage cheese wash water in addition to light froth foams associated with over-aeration.

9. Relatively high COD levels in treated waste waters, with BOD-COD ratios of less than 0.1 in some cases.

10. Frequent clogging of diffuser-type areators and sludge breakup.

11. Poor sludge filtration characteristics.

Table 18. BOD_5/COD Relationships in Raw and Treated Dairy Plant Wastes from Survey of Industrial Dairy Plants

Products Manufactured	Raw Dairy Plant Wastes			After Primary Treatment			After Secondary Treatment		
	BOD_5	COD	BOD/COD	BOD_5	COD	BOD/COD	BOD_5	COD	BOD/COD
Milk Cottage Cheese	3300	3379	.97	---	---	---	---	---	---
Milk Cottage Cheese	3700	7071	.52	145	400	.36	15	100	.15
Milk Yogurt Cottage Cheese	750	850	.88	400	600	.67	80	250	.32
Cottage Cheese Milk	2863	6500	.44	---	---	---	266	700	.38
Milk Cottage Cheese Ice Cream	3200	9000	.41	145	430	.33	15	175	.08
Milk Ice Cream Butter Cottage Cheese	2168	5300	.40	140	350	.40	35	250	.14
Milk Ice Cream Cottage Cheese	3750	9000	.41	---	---	---	150	560	.26
Milk Ice Cream Cottage Cheese	3200	4150	.51	---	---	---	---	---	---
Ice Cream	140	350	.40	---	---	---	35	250	.14

REFERENCES

1. Adamse, A. D. 1967. Bacteriological studies on dairy waste activated sludge. Meded. LandbHogesch. Wageningen, 66:(6)1-79.

2. Dairy Effluents Sub-Committee on the Milk and Milk Products Technical Advisory Committee. 1969. Dairy effluents. Department of Agriculture and Fisheries for Scotland.

3. Dias, F. F. and Bhat, J. V. 1964. Microbial exology of activated sludge. I. Dominant bacteria. II. Bacteriophages, Bdellovibrio, coliforms, and other organisms. Appl. Microbiol., 12:412.

4. Federal Water Pollution Control Administration. 1967. The cost of clean water. Vol. III-Industrial Waste Profile No. 9-Dairies. Fed. Wat. Poll. Cont. Admin., Publ. No. I. W. P.-9, U. S. Gov. Printing Office, Washington, D.C.

5. Fisher, W. J. 1968. Treatment and disposal of dairy waste waters: A review. Dairy Sci. Abstr., 30:(11)567-577.

6. Fritz, A. 1960. Determination of water pollution by dairy effluent. Milchwissenschaft, 15:(12)609-612.

7. Hoover, S. R. 1953. Biochemical oxidation of dairy wastes. V. A. review. Sewage Ind. Wastes, 25:(2)201-206.

8. Lawton, G. W., Breska, G., Engelbert, L. E., Rohlich, G. A., and Porges, N. 1959. Spray irrigation of dairy wastes. Sewage Ind. Wastes 31:923-933.

9. McKee, F. J. 1957. Dairy waste disposal by spray irrigation. Sewage Ind. Wastes, 29:(2)157-164.

10. Pipes, W. O. 1968. An atlas of activated sludge. Federal Water Pollution Control Administration. U. S. Department of Interior.

11. Porges, N. 1958. Practical application of laboratory data to dairy waste treatment. Fd. Technol., 12:(2)78-80.

12. Reynolds, D. J. 1966. Methods for estimating the strength of dairy effluents. 17th Int. Dairy Congr., 5:773-780.

13. Sarkka, M., Nordlund, J., Pankakoski, M., and Heikonen, M. 1970. Water pollution by Finish dairies. 18th Int. Dairy Congr., I - E, A. 1.2 11.

14. Schulz-Falkenhain, H. 1963. Treatment of dairy waste waters in oxidation ponds. Dte. Molk.-Ztg., 84:1403.

15. Svoboda, M. 1966. On the problem of terminology: Ponds, tanks, lagoons. Vodohospdarske TEI, 8:223.

16. Svoboda, M., and Salplachta, J. 1956. Some observations on the purification of dairy effluent by Geotrichum candidum. Cal. Mikrobiol., 1:(4)176-182.

17. Svoboda, M., Hlavka, M., Salplachta , J., and Stelcova, D. 1962. Study on the quantity and pollution of dairy effluent in Czechoslovakia. Sb. vys. Sk. Chem,-technol. Praze, Potravin Technol., 6:(2)139-168.

18. Trebler, H. A., and Harding, H. G. 1949. United States trends in disposal of dairy waste waters. 12th Int. Dairy Congr., 3:Sect, 3, 688-697.

19. United States Public Health Service. 1959. An industrial waste guide to the milk processing industry. U. S. Public Health Service Publ. No. 298.

20. Wallgren, K., Leesment, H., and Magnusson, F. 1967. Investigations on irrigation with dairy waste water. Meddn. svenska Mejeriern. Riksforen., 85:20.

21. Walzholz, G. 1967. Dairy effluent. Dte. Molk. Ztg., 88:(42)1722-1724, (43)1778, (44)1811, (45)1849-1850, (46)1888-1889, (47)1926-1927, (48) 1960-1962.

22. Walzholz, G., and Pester, A. 1960. Engineering problems in the collection and evaluation of dairy effluent. Dte. Molk.-Ztg., 81:(51/52)1886-1889.

23. Zack, S. I. 1956. Trickling filter treatment of wastes at two milk processing plants. Sewage Ind. Wastes, 28:1009-1019.

24. Zall, R. R., and Jordon, W. K. 1969. Monitoring milk plant waste effluent a new tool for plant management. J. Milk Fd. Technol., 32:(6)197-202.

ANAEROBIC-AEROBIC PONDS FOR TREATMENT OF BEET SUGAR WASTES

by

William J. Oswald, Clarence G. Golueke, Robert C. Cooper, and
Ronald A. Tsugita*

This paper is designed primarily to review the most significant results from the last two years of a four-year study of a pilot scale ponding system for beet sugar flume water treatment at Tracy, California. Results of the first two years of the study have been presented previously in a technical paper(1) and in more detail in the first progress reports.(2) The material to be presented herein is drawn from a more recent technical paper(3) and from the final engineering report for this study,(4) in which the study and the results are described in much greater detail than is possible in this brief resume.

The system was constructed near the Holly Sugar Factory in Tracy for the purposes of the study, and consisted of an influent pump, a DSM screen, a 2-hour mud settling tank, an influent volume meter with a series of three ponds, a recirculation system designed to draw water from the third pond of the series and to inject it with the influent at a metered rate, an effluent meter and pump. The three ponds consisted of a 1-acre surface area unit with a maximum water depth of 14 feet, a 2-acre surface area unit with a maximum water depth of 7 feet, and a 3-acre surface area unit with a maximum water depth of 4 feet. Although their names did not always reflect such conditions, the three ponds were referred to as "Anaerobic," "Facultative," and "Aerobic" in the order described. Each ponding element was designed so that the water depths could be decreased to about 2 feet below the maximum so that a range of depths could be explored. The physical appearance and arrangement of the system is shown in Figure 1. The system was equipped for automatic monitoring of sunlight and air and water temperature. A complete chemical laboratory was maintained at the plant site for analytical work.

During the first two years of the study the three ponds -- anaerobic, facultative, aerobic -- were operated in series with variable loading and recirculation. The results indicated that most of the BOD was removed in the primary (anaerobic) pond and that the additional ponds added little to the BOD removal in spite of their greater surface area. On the other hand, the primary anaerobic pond was always malodorous, the odor increasing with increased loading between 500

---

*Respectively Professor of Sanitary Engineering, Research Biologist and Associate Professor of Public Health, University of California, Berkeley, and Senior Engineer, James M. Montgomery Consulting Engineers, Lafayette, California.

Preceding page blank

and 2,000 lbs of BOD per acre per day. Recirculation from the aerobic pond was found to be beneficial in decreasing odor and improving treatment, providing it was not excessive. Recirculation rates of three or four times the influent rate tended to shorten detention times, force loading forward, and diminish the quality of the final effluent from the system.

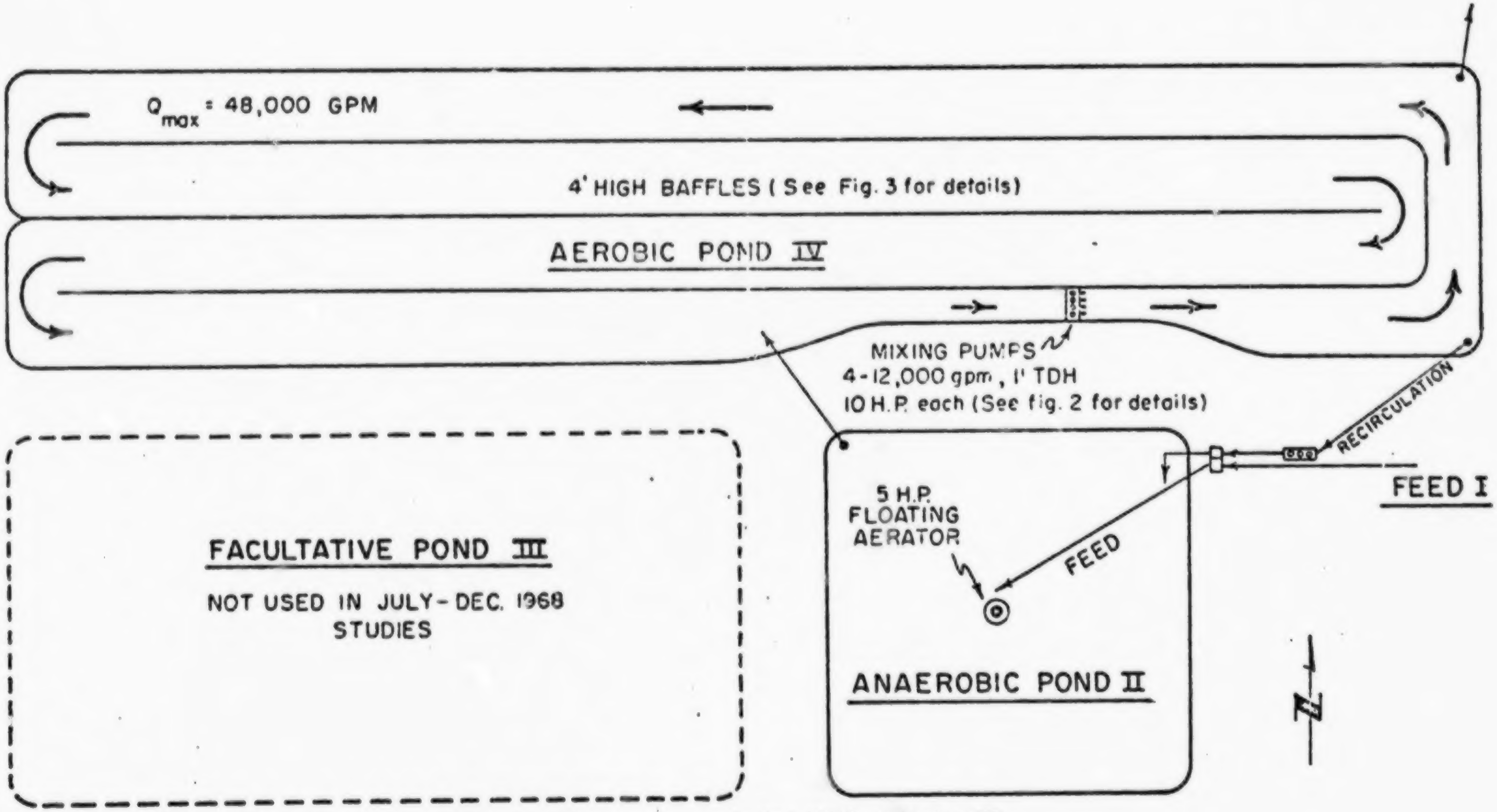
The major conclusions of the earlier study were that it is not possible to operate a ponding system for flume water wastes without odor in the absence of relatively large quantities of molecular oxygen. Thus, systems involving aeration by mechanical aerators or by photosynthetic oxygenation required investigation. Controllable growth of algae in the aerobic pond essential to photosynthetic oxygenation is dependent on controlled mixing and a balanced nutrition for the algae.

Despite generally favorable BOD removal in the system, the three-pond system as it was applied in the first study would not be suitable for a routine application to factory wastes simply because waste treatment was not accomplished to the extent required for an odor-free operation, or for an operation in which an effluent would have to meet reasonably strict discharge requirements. The importance of recirculation is primarily related to conveyance of oxygen, "seed", and nutrients into the primary stages of the system; in dilution of the influent waste with recovered water; and, in forcing stronger wastes forward in the system, thus possibly increasing the efficiency of secondary units. The conclusion of the initial studies was, however, that the optimum rate of recirculation changes with changing conditions in the ponds, and that under some conditions, rates in excess of one or two times the influent volume may be undesirable.

In summary, the work done previously has shown that substantial reductions in solids, BOD, and nutrients may be attained in simple ponds, but that land use, effluent BOD, and odor would be excessive. On the other hand, the first series of studies showed that by using an anaerobic pond in series with other ponds, land use could be decreased. However, effluent BOD and pond odor would still be excessive.

The specific purpose of this second study was to explore mechanisms of aeration and to improve pond design and operation to increase the rates of BOD and odor removal and to further explore methods of decreasing land requirements. Another purpose of the work was to derive design criteria for systems of ponds which would have predictably satisfactory performance over a range of environmental conditions, and which could therefore be applied to meet discharge specifications in a variety of climates.

During the period reported in this paper, three types of systems were studied: an anaerobic pond with aeration, an anaerobic pond with



OPERATING SEQUENCE : Aug 1967 - II only
Fall 1967 - II plus III
Spring 1968 - II plus IV
Fall 1968 - II plus IV

FIGURE I. SHOWING LAYOUT OF PONDS, ARRANGEMENT OF BAFFLES AND MIXING PUMPS IN AEROBIC POND

aeration in series with a facultative pond, and an anaerobic pond with aeration in series with a photosynthetic algae pond. Analytical work in the study was quite detailed. In addition to measuring and maintaining records of pond depth, detention period, recirculation, and mixing, the studies also included measurement of air and water temperatures and light energy input, as well as analyses to determine BOD, COD, total and volatile suspended and dissolved solids, nitrogen, phosphorus, magnesium, calcium, sulfate, and sulfide, algae and other organisms, and algal packed volume. Routine analyses were made according to techniques given in Volume 12 of Standard Methods for Examination of Water and Waste-Water,(5) and modified to meet needs peculiar to the material being tested in the study. Gas production was studied with Bronson(6) gas collectors (shown in Figure 2). Data on methane fermentation were limited to the final series, both because a clearcut methane fermentation did not become established in the ponds, and because gas emission measurements were interrupted by water condensation in the transmission lines from the Bronson collectors to the gas meters in all but the final runs. Although a standard method is available for odor evaluation, this was deemed too time-consuming, and a simplified "direct sniff" method was developed for expressing odor. This was done by establishing six arbitrarily designated characteristic odors: 1 - none; 2 - beets; 3 - other; 4 - cow dung; 5 - H_2S; and 6 - foul. Also, six intensities were arbitrarily estimated: 1 - being a very low intensity and 6 - being a high intensity. The arbitrarily assigned numbers were multiplied together to give an "odor product." The lowest odor product possible is 1 and the highest is 36. A sample which smelled like H_2S and was moderately strong would have an odor product of 5 x 3 or 15. A strong beet smell would have a product of 2 x 6 = 12, and so on.

Nutrient addition to the ponds was studied, but the results were inconclusive.

During the course of the studies, several 24-hour studies were conducted to obtain information on the diurnal rates of oxidation and photosynthesis in the ponds.

In the original conceptual design of this project, it was an objective that the system should be operated under a given set of experimental variables for a period of time until steady state could be attained. One of the annoying problems in the study which seemed to interfere with this objective was a lack of flow control due to persistent clogging and other problems with the feed system. In retrospect after viewing the completed data one realizes that because of load variation hopes of attaining a high degree of control and for reaching a steady state were unrealistic. The fact is that, because of drastic but apparently uncontrollable momentary daily and seasonal changes in factory waste strength no steady state could have been attained in these studies regardless of flow control, nor can one expect a true steady state to ever be maintained in a plant processing the wastes of a beet sugar factory.

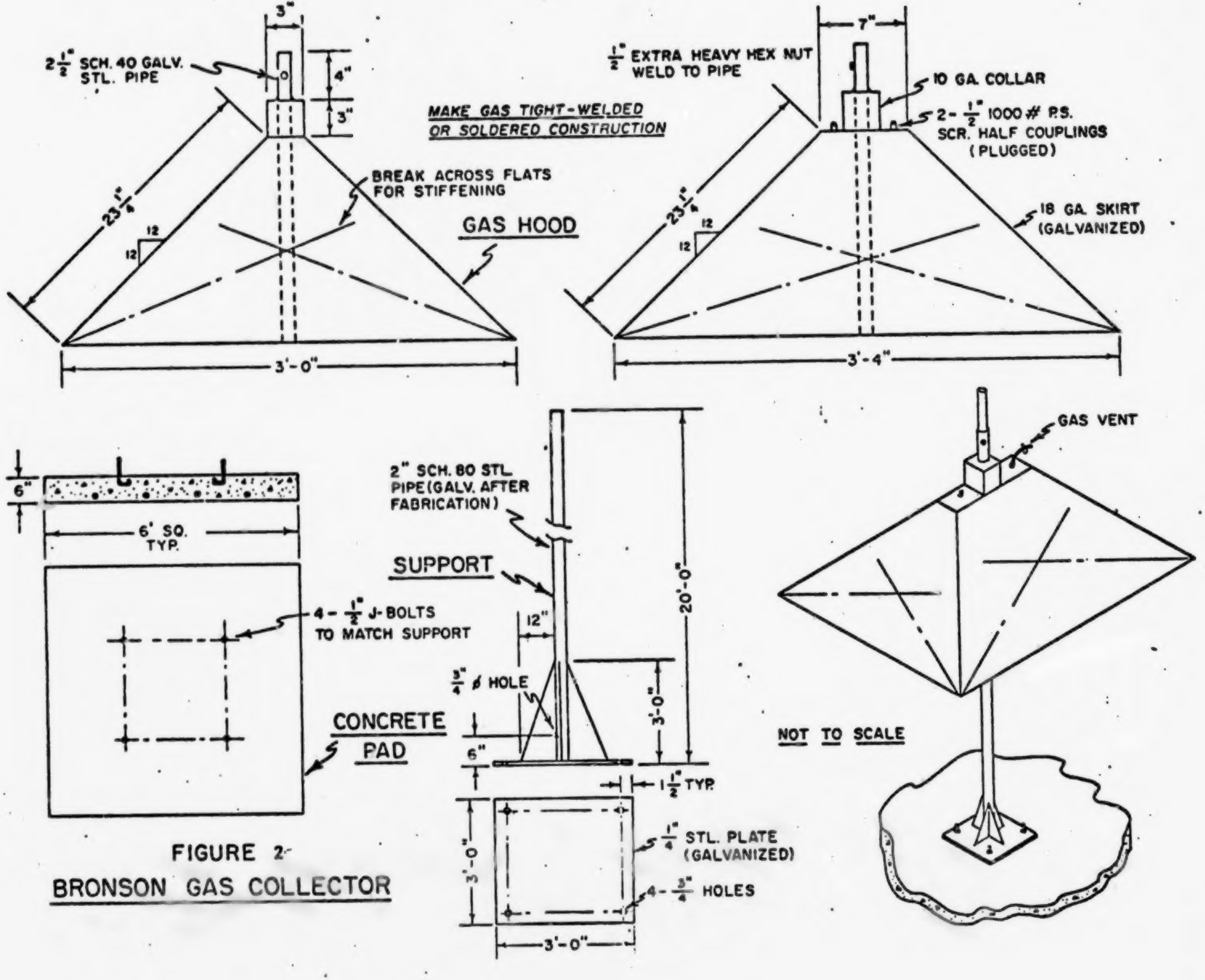

3"
$2\frac{1}{2}$" SCH. 40 GALV. STL. PIPE
4"
3"
$23\frac{1}{4}$"
12
12
BREAK ACROSS FLATS FOR STIFFENING
3'-0"
MAKE GAS TIGHT-WELDED OR SOLDERED CONSTRUCTION
GAS HOOD
7"
$\frac{1}{2}$" EXTRA HEAVY HEX NUT WELD TO PIPE
10 GA. COLLAR
2-$\frac{1}{2}$" 1000 # P.S. SCR. HALF COUPLINGS (PLUGGED)
$23\frac{1}{4}$"
12
12
18 GA. SKIRT (GALVANIZED)
3'-4"
6"
6' SQ. TYP.
4-$\frac{1}{2}$" J-BOLTS TO MATCH SUPPORT
CONCRETE PAD
2" SCH. 80 STL. PIPE (GALV. AFTER FABRICATION)
SUPPORT
12"
$\frac{3}{4}$" ⌀ HOLE
6"
20'-0"
3'-0"
$1\frac{1}{2}$" TYP.
$\frac{1}{4}$" STL. PLATE (GALVANIZED)
4-$\frac{3}{4}$" HOLES
3'-0"
3'-0"
GAS VENT
NOT TO SCALE

FIGURE 2

BRONSON GAS COLLECTOR

EXPERIMENTAL

As noted previously the experimental work involved a study of the waste assimilated by the anaerobic pond with a 5 hp floating aerator; an appraisal of the combined action of the aerated anaerobic and facultative pond in series; a study of the oxygenation capacity of the algae pond without mixing; and the combined action of the aerated anaerobic and mixed algae pond in series. During the series studies, it was intended to operate the system with a continuous feed rate and a continuous recycle rate; but as noted above, because of interruption in flow and changes in waste strength, it was only possible to measure the flows and loads as they occurred, and loading rates were computed on the basis of such flow and BOD data for arbitrarily specified monthly time periods. These arbitrary loadings, together with other specified conditions, are presented in each section together with the results.

Before reviewing the process results, it is worthwhile to present the available data on the mean value of all of the biochemical parameters studied for Tracy flume water over the entire four-year period of the study, 1965 to 1968 inclusive. The detailed analytical information accumulated on waste composition during the period was averaged, and the averages tabulated in Table 1. Variance was also determined for some of the parameters. As is evident from the table, variance (σ/[illegible]) was often in excess of 1000 percent, and this degree of variance is evidently one of the factors which has led to serious difficulties in the treatment of beet sugar factory wastes. In addition to the large random momentary variation and daily variations in waste strength and composition, the data evidenced an even stronger seasonal variation which will become evident to the reader when results are presented for parameters such as COD and nutrients.

Aeration in the Anaerobic Pond

An anaerobic pond is normally designed to avoid the intrusion of oxygen, but the severe odors in the anaerobic pond encountered during the earlier studies led us to explore the use of a surface aerator for odor control. The hope was that surface aeration would not interfere with methane fermentation. The aerator was a 5 hp floating unit(7) located in the anaerobic pond, as shown in Figure 1. During a prior series of tests the anaerobic pond had been heavily loaded; and following several weeks without influent, the residual BOD was 330 mg/l and the pond void of dissolved oxygen. Prior to the study, the odor intensity level of the anaerobic pond was above 12, and was characterized by a foul hydrogen sulfide stench that had barely improved after standing several weeks. As indicated graphically in Figure 3, after three days of aeration with the new aerator, the odor intensity dropped to a level of 4. The odor quality became that characterized as "cow dung." By the seventh day, the odor intensity level had dropped to 1.0, which was the lowest value on the arbitrary scale used.

TABLE I

Mean Values for Certain Analytical Parameters of Holly-Tracy Flume Water - 1965 - 1968

(Following 16 mesh DSM screening and 1.5 hr. sedimentation)

Parameter	Units	Value	Variance
Total Nitrogen (N)	mg/1	16.4	--
Ammonia (N)	"	6.3	--
Nitrate (N)	"	2.6	--
Chlorides	"	400 *	--
Sulfate	"	210.0	--
Alkalinity ($CaCO_3$)	"	538.0***	--
Sulfide	"	0.68	--
Phosphate (P)	"	3.4	--
Calcium	"	178.0	--
Magnesium	"	66.0	--
Sodium	"	222.0**	--
Potassium	"	88.0**	--
BOD (unfilt.)	"	930.0	--
COD (unfilt.)	"	1601.0	--
COD (filt.)	"	1195.0	--
Suspended Solids	"	1015	11269
Suspended Volatile	"	360	7140
Suspended Ash	"	655	6348
Dissolved Solids	"	2209	6016
Dissolved Volatile	"	1139	2764
Dissolved Ash	"	1070	7754
Total Solids	"	3224	14979
Total Volatile	"	1499	4456
Total Ash	"	1725	8328
Sugar	"	1.25	0.25
Dissolved Oxygen	"	0.0	
Physical factors			
pH		7.06	1.8
Light Penetration	cm	45.6	17.8
Specific Conductance µ mhos	cm	300	299

*Based on specific conductivity
**Single values
***By difference

The COD and BOD results for this aeration study shown graphically in Figure 3 indicate that in the presence of oxygen, oxidation of substances occurred rapidly in the system. As is evident from the graph, the BOD which was initially 330 mg/l declined to 18 mg/l on August 28; whereas the COD steadily increased from 390 to 590 mg/l during the first four days, and then declined to 134 mg/l by August 28. The initial increase in COD was apparently due to the mixing pump bringing into suspension colloidal material which exerted a COD but not a BOD. A COD of 100 probably approaches the lowest COD likely to be encountered with stabilized beet sugar waste.

During the period August 1 to August 16, no dissolved oxygen was detected in the system. After August 19, dissolved oxygen began to appear in the water during the afternoons, although it would be at zero concentration in the mornings. This indicates that after August 19 photosynthetic activity was beginning to replenish oxygen in the system even while oxygen was being introduced by the aerators.

During the period August 1 to August 16, the BOD decreased from 335 mg/l to 100 mg/l. Thus in 15 days, the total reduction was 235 mg/l. Inasmuch as during this period the volume of the anaerobic pond was about 2.5 million gallons, the total amount of BOD oxidized was 235 x 2.5 x 8.34 = 4,900 lbs, or 327 lbs per day. Assuming that during this period natural re-aeration contributed 20 lbs per day (the surface area being 1 acre), the aerator must have contributed 307 lbs per day, or 2.54 lbs per hp-hr. This rate is precisely that published by the manufacturer(7) -- namely, 3.2 lbs of O_2 per kw. hr. at 0 dissolved oxygen.

The rate of change of COD was somewhat higher after the first five days, but the overall rate, neglecting the initial "hump", corresponds well with the change in BOD. The initial hump probably resulted from the disturbance of bottom substances which had a COD but little measurable BOD. It should be noted that about 20 days were required to satisfy the pond BOD and attain free molecular oxygen, and that the odor level had dropped to 1 when about one-third of the time had elapsed. This corresponded to the satisfaction of about one-third of the BOD.

During the period of mechanical aeration without loading, the pH in the pond slowly decreased from 7.6 to 7.1 between August 1 to August 10, and then increased to 7.9 in the period August 11 to August 18. The increase probably was due to photosynthetic activity.

Aerated Anaerobic and Facultative Pond in Series

In the next series of experiments, the aerated anaerobic and facultative ponds were operated in series. Key conditions and results from this experimental series are summarized in Table 2. No recirculation was applied. Application of waste to the anaerobic pond was at the initial rate of 25 gpm. The BOD of the influent ranged from 1308 to 1639 ppm. During several periods in these

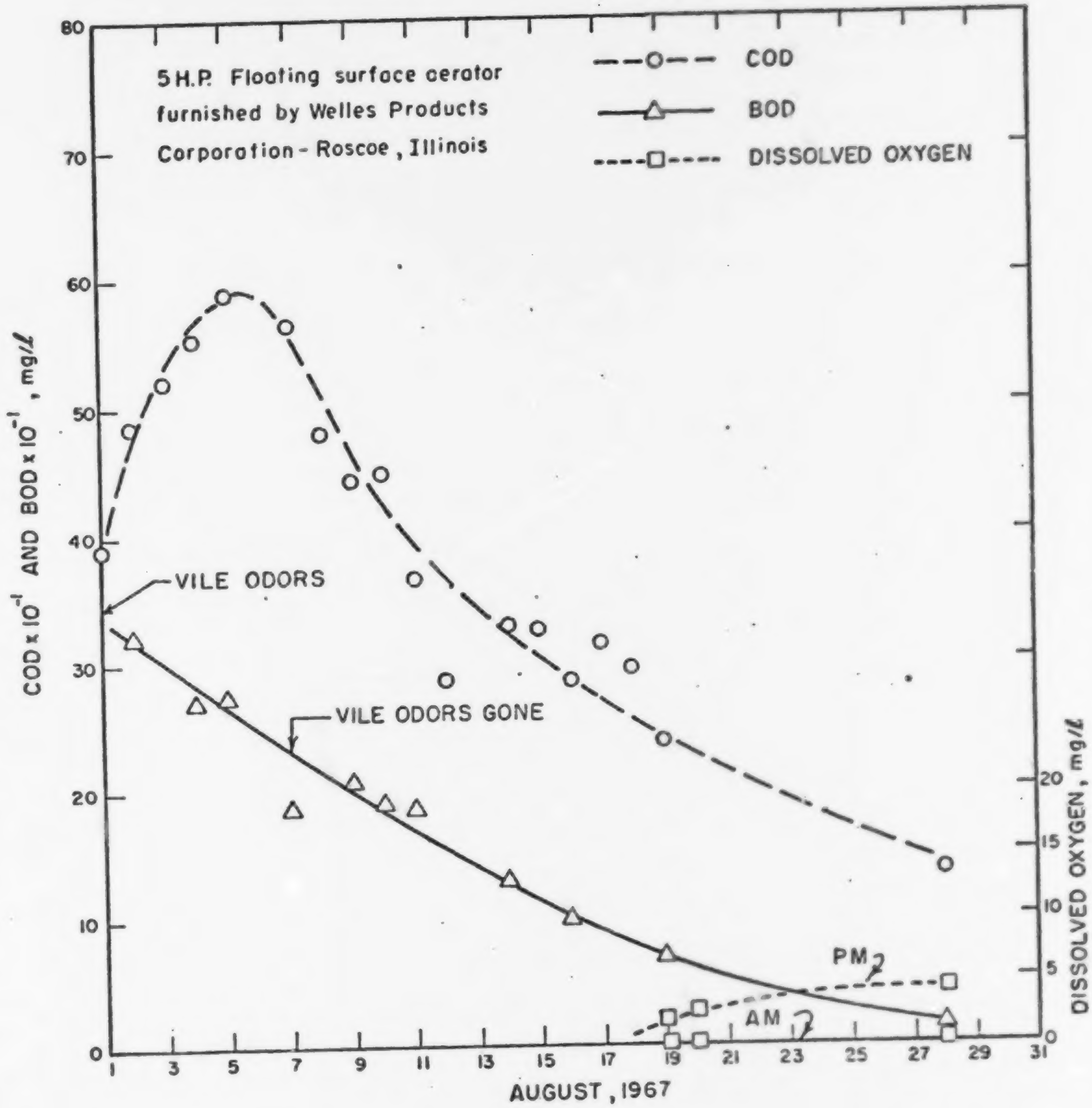


FIGURE 3 CHANGE IN COD, BOD, AND D.O. IN ANAEROBIC POND DURING SUSTAINED AERATION WITH 5 H.P. FLOATING SURFACE AERATOR

experiments, the waste had a strong foul odor, a brown color, and a nitrogen content as high as 64 mg/l -- indicating the intrusion of Steffen waste into the flume water. As the experiments progressed the effluent BOD from the anaerobic pond began to increase, and rose from 18 to 53 mg/l within a week. It reached 129 mg/l by the end of the 25 gpm run. During the same time, the COD rose from 134 to 228 mg/l. Odor at first increased and then declined. At the feed rate of 25 gpm, the average organic load entering the anerobic pond was estimated to be between 400 and 500 lb/day/acre, exceeding by 75 to 175 lbs the daily aeration capacity of the 5 hp floating aerator. Frequent interruptions in flow due to influent pumping failures at first permitted the aerator to maintain a small residual of dissolved oxygen in the surface layers of the anaerobic pond, and kept the odor intensity level down to about 5. However, when the loading rate was increased to 50 gpm, all dissolved oxygen disappeared from the system and the odor level in the anaerobic pond rose to 9.

According to Table 2, loadings varied from 900 to 0 lbs/day/acre. Generally speaking, most of the BOD was removed in the anaerobic pond and odor levels in the anaerobic pond were not as severe as they had been without aeration.

Because of the high BOD removals in the anaerobic pond, loadings to the facultative pond were always less than 180 lbs per day. Effluents from the facultative pond varied from 47 to 140 mg/l BOD, with little apparent relationship to applied BOD. Odor levels in the facultative pond were always 3 or less. During this period, the facultative pond contained a rich culture of the blue green algae Oscillatoria limosa which remained in suspension, and apparently in some cases retained or possibly fixed nitrogen to the extent that nitrogen concentration in the facultative pond was higher than those in the anaerobic pond. O. limosa concentration in the facultative pond reached concentrations approaching 100 mg/l. Nitrogen concentrations in the anaerobic pond were always less than those in the influent -- a fact which confirms the high nitrogen removals in the anaerobic pond reported in the Progress Report of earlier work.(1) The degree of nitrogen removal in the anaerobic pond was, however, somewhat less than had occurred previous to the introduction of the surface aerator.

Photosynthesis and Respiration

Prior to the activation of a mixing system in the aerobic pond, a study was made to determine the rates of photosynthesis and oxidation in the unmixed pond. This determination was made by means of a 24-hour study. Such 24-hour studies of dissolved oxygen and temperature may be extremely valuable in systems undergoing oxidation and photosynthetic oxygenation because the data may permit an evaluation of the in situ rates of oxygen use and the in situ rates of oxygen production. No dark bottles or other devices are needed, with no disturbance of the system. One requirement for the success of such a 24-hour study is the attainment of oxygen supersaturation

TABLE 2

RESULTS

1967 Aerated Anaerobic Pond Plus Facultative Pond With No Recirculation

Pond	Run	Flow gal/min	Load lbs day	BOD mg/l	COD mg/l	Vol Sol mg/l	Total N mg/l	Odor Product
Inf	13	25	--	1500	1776	1450	22	12
An	"		450	129	321	491	15.2	5
Fac	"		39	79	370	584	20.5	3
Inf	14	50	--	1490	1814	1172	38.9	16
An	"		900	101	276	401	17.7	9
Fac	"		61	77	493	625	24.3	3
Inf	15	75	--	983	1532	781	23.2	6
An	"		900	200	402	412	20.4	10
Fac	"		180	113	512	631	23.6	3
Inf	16	0	--	726	--	454	--	6
An	"		--	314	452	454	15.7	10
Fac	"		--	140	550	508	21.7	3
Inf	17	50	--	1202	1455	1065	35.0	4
An	"		720	184	371	470	21.4	14
Fac	"		110	64	408	563	20.7	3
Inf	18	50	--	665	1220	882	25.8	--
An	"		--	142	402	495	25.2	--
Fac	"		--	47	426	583	21.6	--

at some point in time. The method is based on the fact that at the points in time that the dissolved oxygen concentration of the pond is equal to the saturation concentration for that temperature, no exchange of oxygen gas can occur with the atmosphere and consequently the observed rates of change in oxygen concentration are independent of atmospheric gas exchange, and are a function solely of the difference between the rates of photsynthetic oxygen production and microbiological respiration. In spite of several efforts, supersaturation was reached in only one 24-hour study, but this was sufficient to permit the desired determinations. During that study the applied BOD load to the aerobic pond was about 60 lbs/day/acre, and the solar energy input was about 200 calories per cm^2 per day.

Results of that run are plotted in Figure 4. From the figure it may be observed that the exchange independent rate of respiration was 0.467 mg O_2/liter per hour, and the mean photosynthetic rate at the surface netted 1.16 mg/l/hr. The gross surface photosynthetic rate including respiration was therefore 1.62 mg/l/hr. From these data the rate of oxygen use by the pond was 86 lbs/day/acre. The net surface photosynthetic oxygen production was 214 lbs/day/acre, and the gross surface rate 300 lbs/day/acre. Inasmuch as, due to light absorption, the photosynthetic rate decays logrithmically with depth, the average rate with depth would be about one-third the surface rate or about 100 lbs/day/acre. The apparent photosynthetic efficiency of the algal pond, assuming a sunlight energy input of 200 cal/cm^2 per day, was then about 2.3 percent. As is to be expected, this rate of oxygenation was slightly greater than the rate of deoxygenation based on the respiration rate, a fact that is also evidenced by the observation that the oxygen level was continuously near saturation. One may further conclude that inasmuch as the system was supersaturated during daylight hours and barely fell below saturation at night, there must have been a net export of O_2 from the system, indicating that it was underloaded for the conditions obtaining. A corollary is that a BOD loading of 100 lbs/day/acre could have been applied at this time with no deterioration of the system. This rate, however, probably exceeds the maximum safe design, particularly in view of the fact that beet sugar wastes frequently contain pigments and colloids which interfere with the penetration of light.

Aerated Anaerobic Pond in Series with a Mixed Aerobic Pond

In spite of the fact that photosynthetic oxygenation can frequently provide 100 lbs of oxygen or more per acre per day in an unmixed pond and when sunlight, temperature, and waste quality permit, there are many times when the ponds become stratified, sunlight is diminished, or the wastes highly pigmented, and photosynthesis cannot meet the oxygen demand of a heavily loaded system. Under such conditions a supplementary method of oxygenation is essential if odors are to be avoided and a good quality effluent to be obtained.

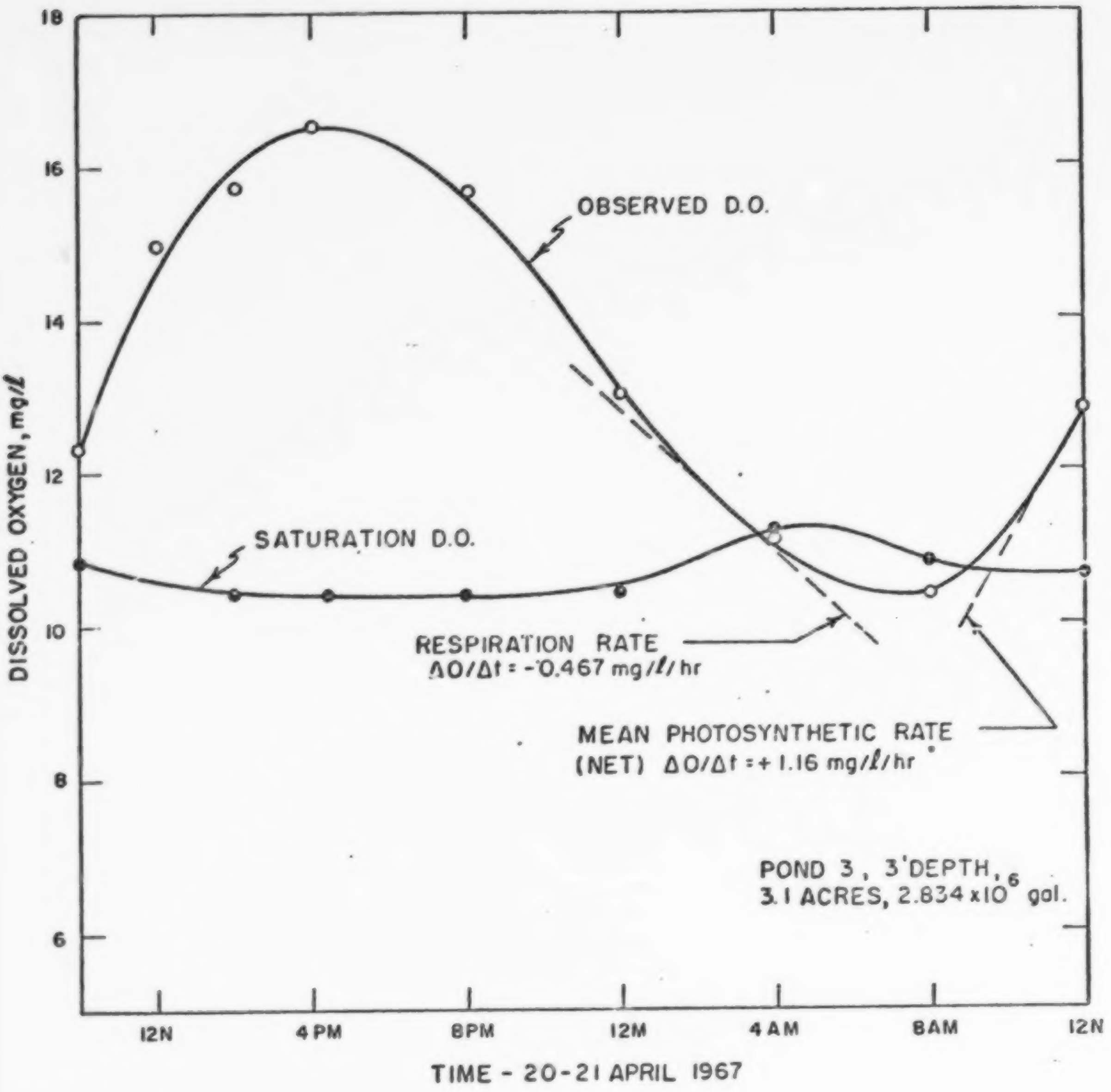


FIGURE 4 DISSOLVED OXYGEN VS TIME OF DAY

The simplest form of supplementary aeration, and one that is highly compatible with photosynthetic oxygenation, is a flow-mixing system. Such a system maintains algae and their nutrients in suspension and through eddy diffusion provides surface oxygenation when photosynthesis is inactive. As noted previously, the final series of experiments reported herein involved such a flow-mixing system in series with the surface aerated anaerobic pond. As was shown in Figure 1, the pond was equipped with flow diversion baffles and flow was induced by means of four low head-high volume propeller pumps. These pumps were fabricated by the University shopsmiths from components readily available on the market. A schematic diagram of the pumps is shown in Figure 5, and of the entire system is shown in Figure 6.

The system shown was operated on a sustained basis for the entire five months of the 1968 Fall campaign. Climatological conditions are summarized in Figure 7, and flow loading and BOD removal conditions for the system are shown in Table 3. The letters I, E, R, and T refer to the flow lines shown in Figure 6; the letters An and Al refer to the anaerobic and algae ponds.

Evidence presented in Table 3 indicates that the overall system attained BOD removal efficiencies varying from 84 percent to 98 percent. Overall COD and BOD values for the system are presented in Table 4 as a function of pond and month. Unfiltered BOD values are plotted in Figure 8. As is evident in the figure, 80 percent or more BOD removal was always attained. Values for the pH of the waste and anaerobic and aerobic pond effluents are shown in Figure 9. The Figure evidences the extreme variation of over 5 pH units observed for beet sugar flume water.

The aerobic pond was subject to considerable variation in dissolved oxygen, as is evidenced by the P.M. dissolved oxygen levels plotted in Figure 10. Because of the presence of dissolved oxygen,the aerobic pond never had an objectionable odor.

Odors were, however, present in the anaerobic pond in spite of the aeration applied. That certain of these odors resulted from the reduction of sulfate, is evidenced by the sulfate value as a function of pond and month, shown in Figure 11. Sulfate reduction was directly related to water temperature, since its rate decreased during the Fall. The relationship between sulfate reduction and temperature observed may be expressed as $R\% = 55 + 2(T-10)$(1) in which R is the percent reduction in sulfate and T is the temperature in °C. A statistical analysis indicated that much of the sulfide released as a result of sulfate reduction combines with magnesium. This is probably an organic complex of magnesium sulfide. It characteristically imparts the dark ink-like color typical of anaerobic beet sugar waste.

Inasmuch as there was evidence of a clear relationship between loading and odor, an effort was made to correlate the two. The results of this correlation are shown in Figure 12. The available evidence (with two exceptions) indicates a positive and linear relationship between odor

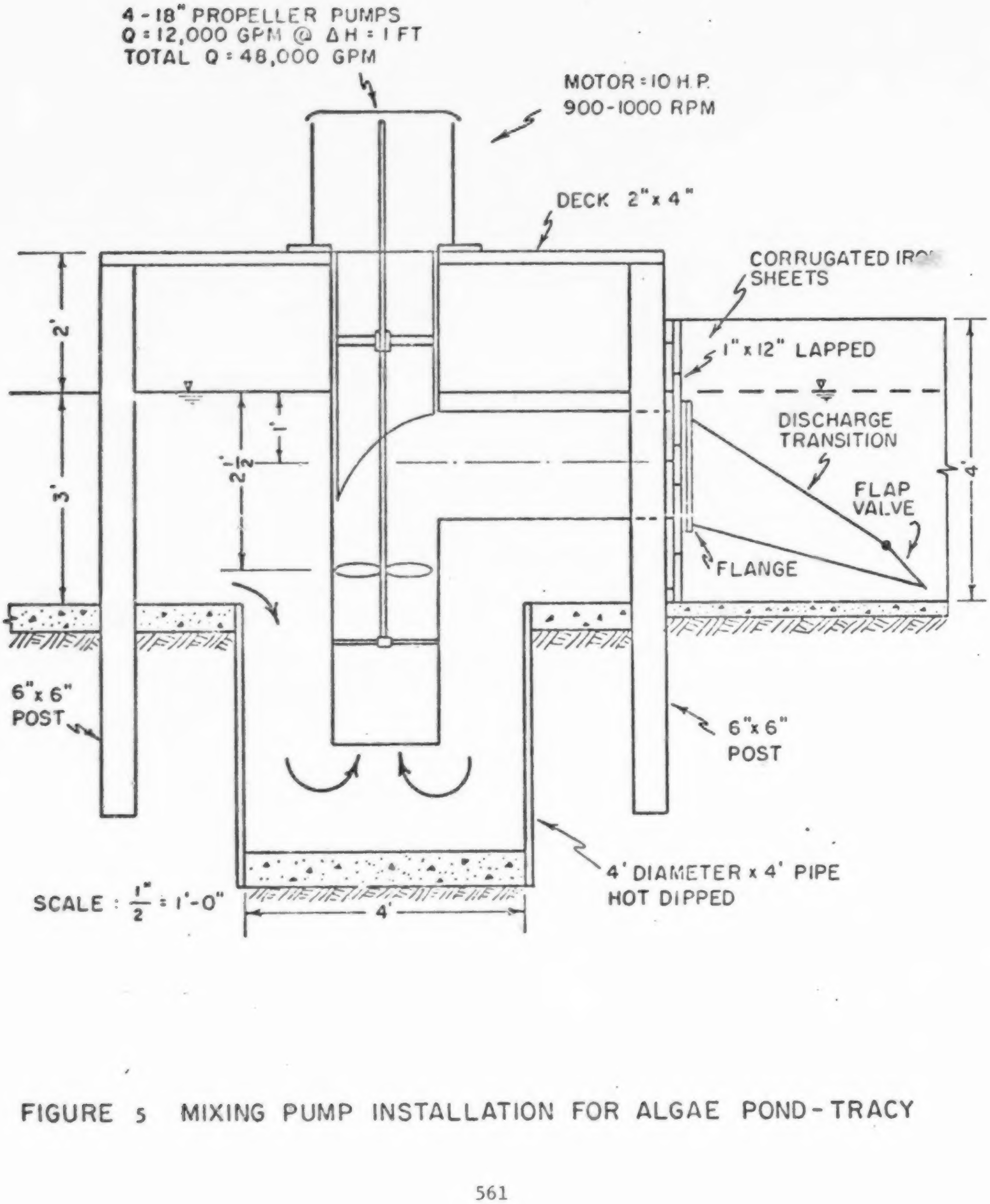


FIGURE 5 MIXING PUMP INSTALLATION FOR ALGAE POND-TRACY

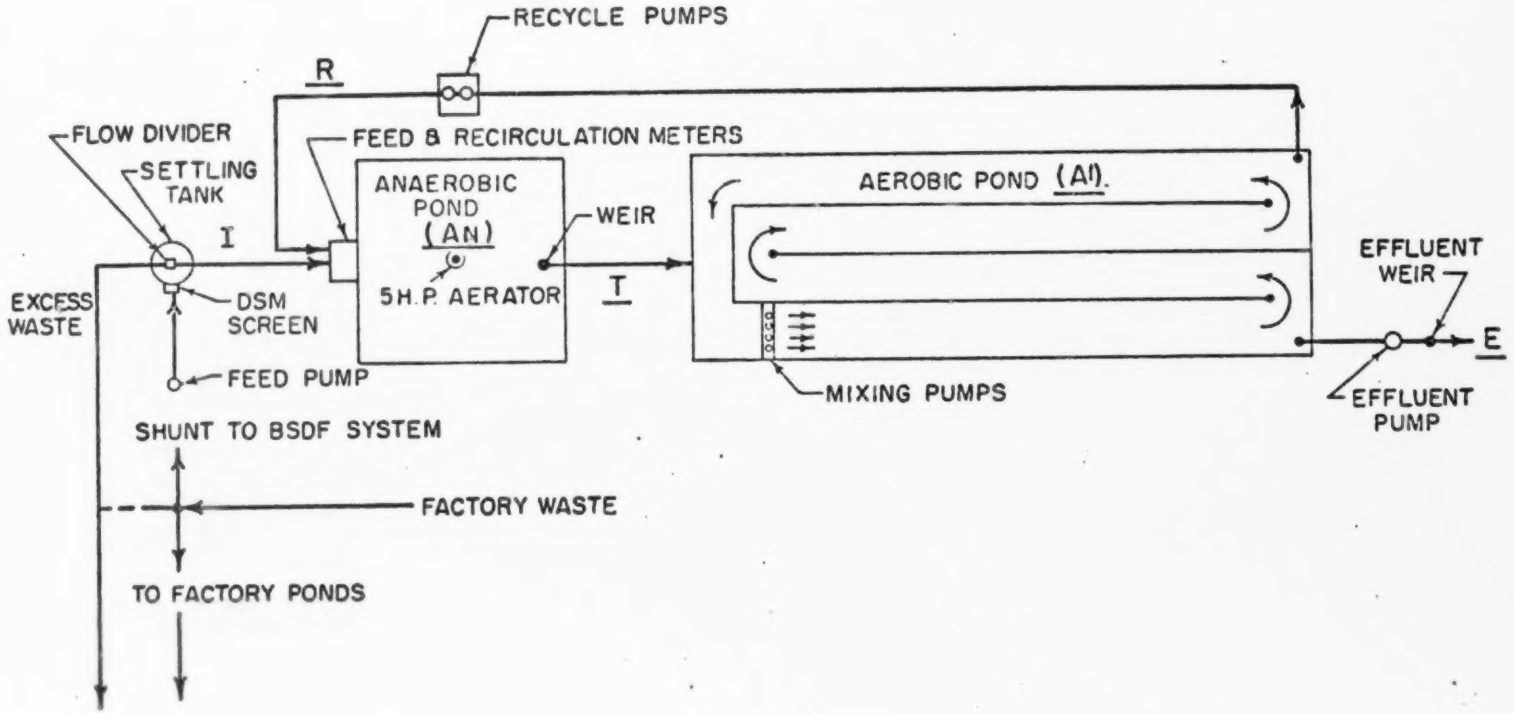


FIGURE 6 SCHEMATIC DIAGRAM OF SYSTEM AS APPLIED IN AERATED ANAEROBIC PLUS MIXED ALGAE POND SERIES

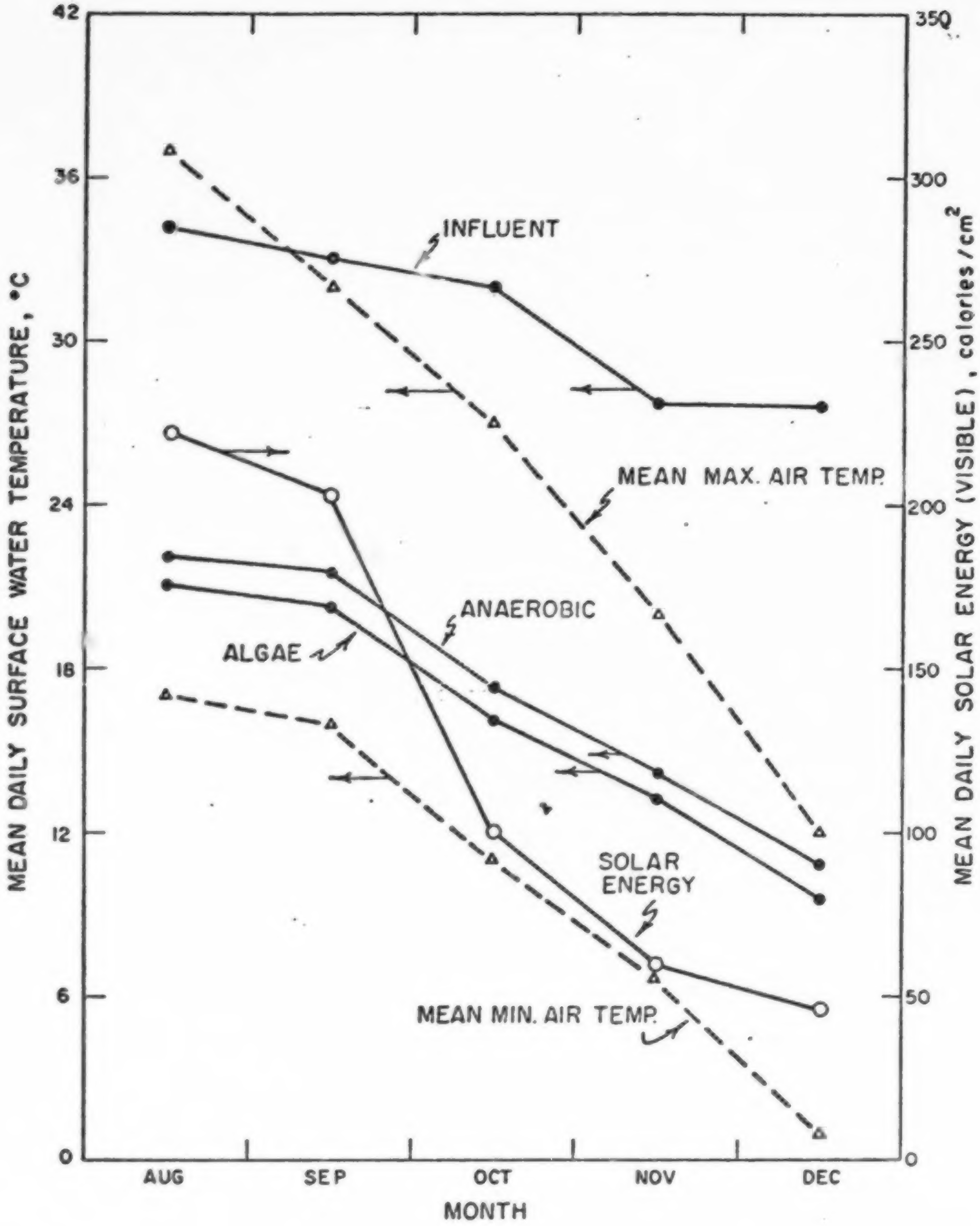


FIGURE 7 MEAN VISIBLE SOLAR ENERGY AND SURFACE WATER TEMPERATURE, MAXIMUM AND MINIMUM AIR TEMPERATURE AS A FUNCTION OF MONTH

TABLE 3

Monthly Mean Flows BOD Values and Performance Data for Anaerobic-Algae Pond in Series

Month 1967	Jul	Aug	Sep	Oct	Nov	Dec
I* Flow GPM (mean)	88	105	75	128	17	82
BOD of I mg/1 (mean)	1180	1440	1260	915	1420	1410
I Load lbs/day	870	1810	1134	1406	290	1380
lbs/acre/day	"	"	"	"	"	"
R* Flow GPM (mean)	--	148	148	148	23	82
BOD of R mg/1 (mean)	73	142	191	82	81	85
R Load lbs	--	255	341	147	22	83
An* Load lbs/day influent + recycle	--	2060	1475	1553	312	1463
T* Flow GPM (mean)	--	100	183	195	26	113
BOD of T mg/1 (mean)	151	268	245	133	176	114
Al* Load lbs/day	--	322	538	313	54	156
lbs/acre/day		107	179	104	18	52
An Removal lbs/day	--	1738	937	1240	258	1307
E* Flow GPM (mean)	--	22	90	76	33	36
BOD of E mg/1 (mean)	73	142	191	82	81	85
Load Disch lbs/day	--	38	207	75	32	37
E + R lbs/day	--	293	548	222	54	120
Al Rem lbs/day	--	29	-10	91	00	36
lbs/acre/day		10	- 3	30	00	12
BOD Rem Eff An %	--	95.5	64	80	83	39
BOD Rem Eff Al %	--	9.0	-1.8	29	00	23
Overall Eff % of BOD Removal		98	84	95	89	98

*Letters identified in Figure 6

N.B. All BOD values are ultimate BOD's, i.e. 5-day BOD/.684

TABLE 4

Summary of Monthly Mean COD and BOD Values
as a Function of Pond and Month

Month	Samp	Unfilt COD mg/1	Filt COD mg/1	COD/BOD Unfilt	Unfiltered BOD 5-day 20°C mg/1	Unfiltered BOD Ult 20°C mg/1	Unfiltered BOD Ult 20°C lbs/1000 gal	Filt BOD mg/1
Jul[1]	Inf	1482	603	1.85	803	1180	9.85	
	An	261	119	2.54	103	151	1.61	
	Al	150	142	3.00	50	73	0.61	
Aug	Inf	1450	961	1.48	985	1440	12.00	
	An	389	217	2.11	184	269	2.24	
	Al	314	112	3.20	98	143	1.19	13[2]
Sept	Inf	1559	1128	1.81	863	1260	10.50	
	An	630	144	3.78	167	245	2.04	
	Al	544	116	4.17	130	191	1.59	10[3]
Oct	Inf	1570	1180	2.50	625	915	7.60	
	An	750	137	8.25	91	133	1.11	
	Al	656	104	11.90	56	82	0.68	
Nov	Inf	1960	1541	2.01	971	1420	11.80	
	An	715	209	6.0	119	174	1.45	
	Al	610	150	11.0	55	81	0.67	
Dec	Inf	2380	1969	2.47	963	1410	11.75	
	An	759	165	9.80	78	114	0.95	
	Al	579	130	10.00	58	85	0.70	

[1] Values for July are based on single or duplicate tests only

[2] Single sample

[3] Mean of four weekly samples

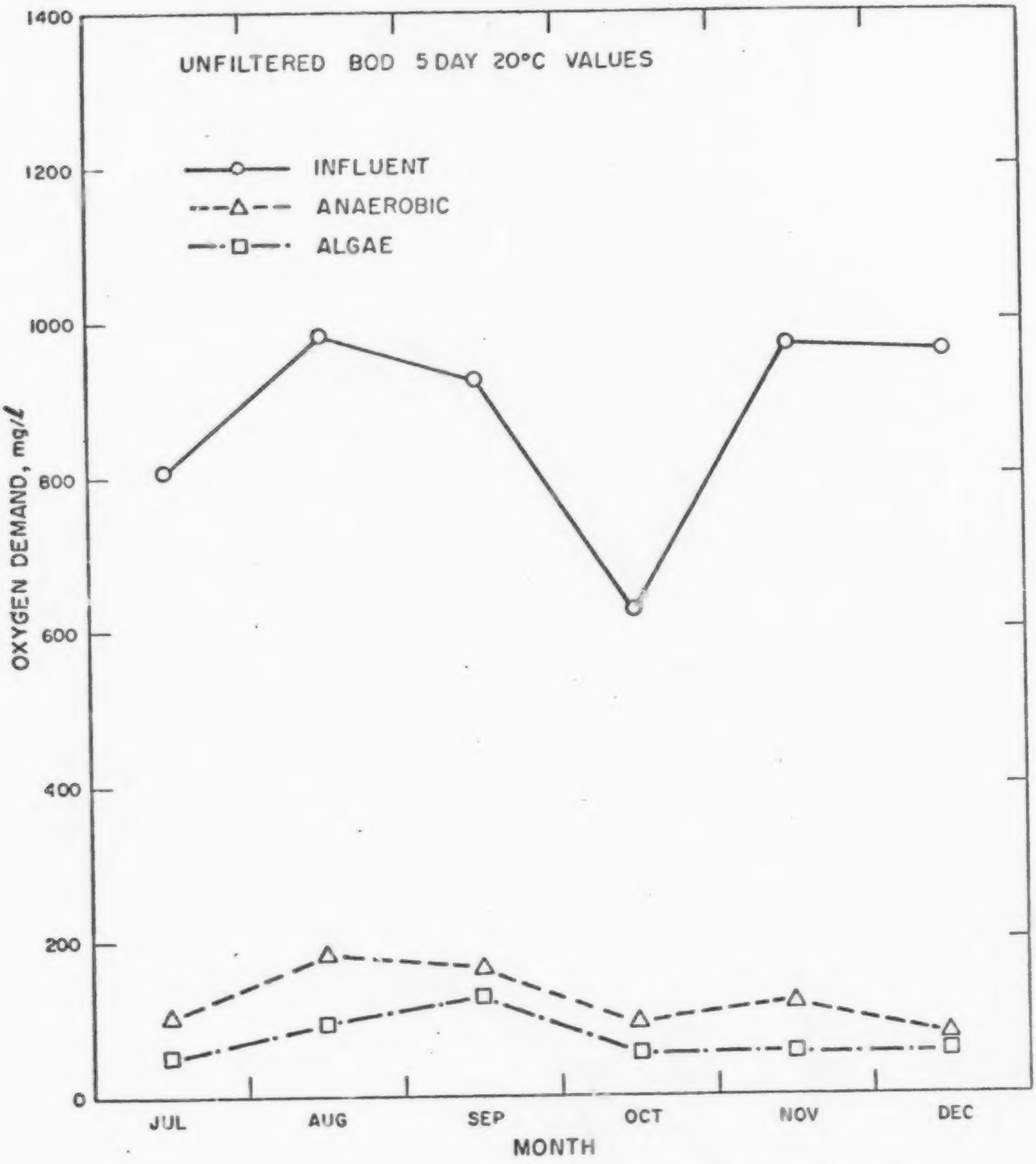


FIGURE 8. MONTHLY MEAN VALUES FOR UNFILTERED BOD AS A FUNCTION OF POND AND MONTH

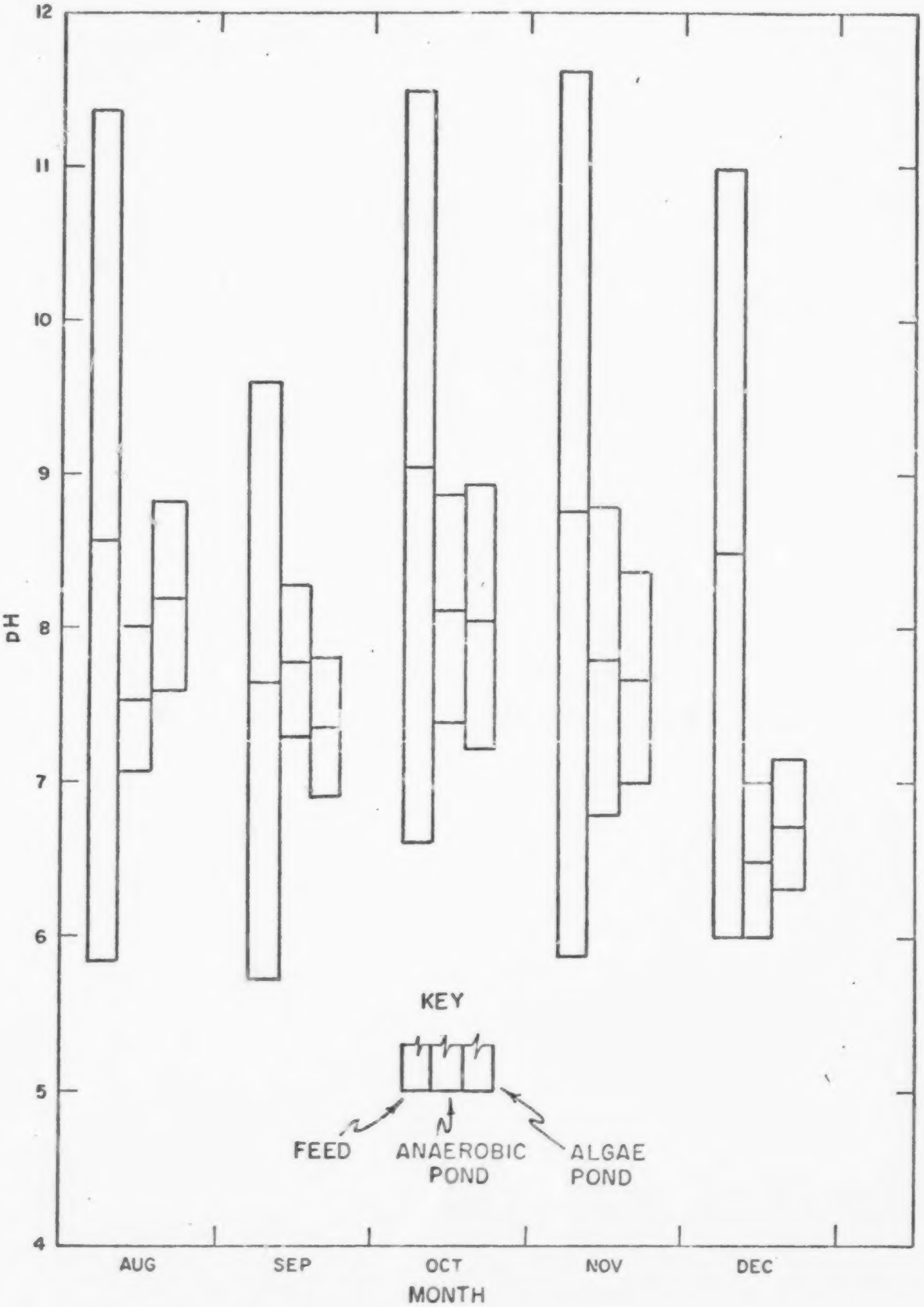


FIGURE 9. EXTREMES AND CENTRAL TENDENCY pH RELATIONSHIP IN INFLUENT, ANAEROBIC AND ALGAE POND AS A FUNCTION OF MONTH

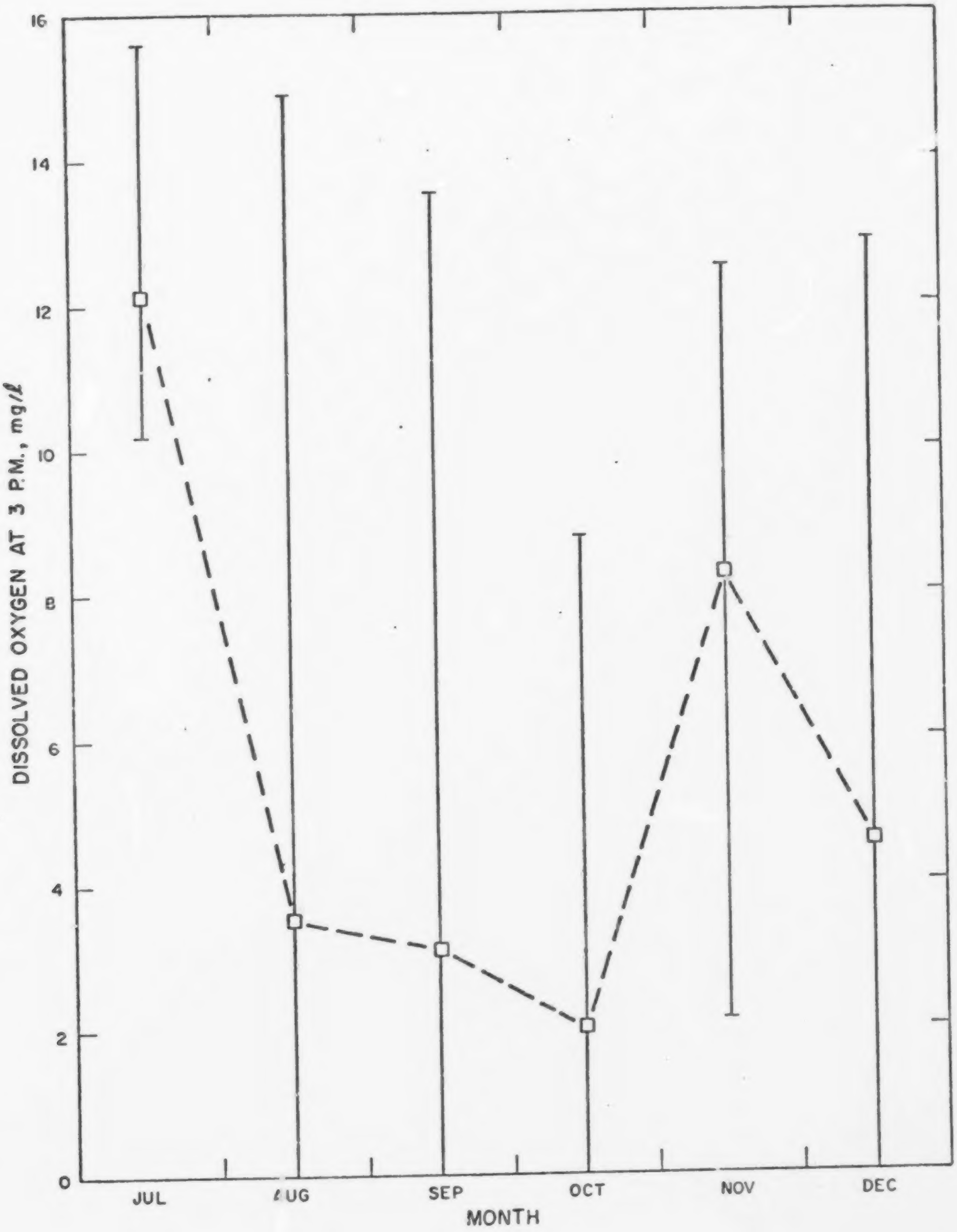


FIGURE 10. MONTHLY MEAN, MAXIMUM, AND MINIMUM DISSOLVED OXYGEN VALUES FOR ALGAE PONDS DAILY AT 3 P.M.

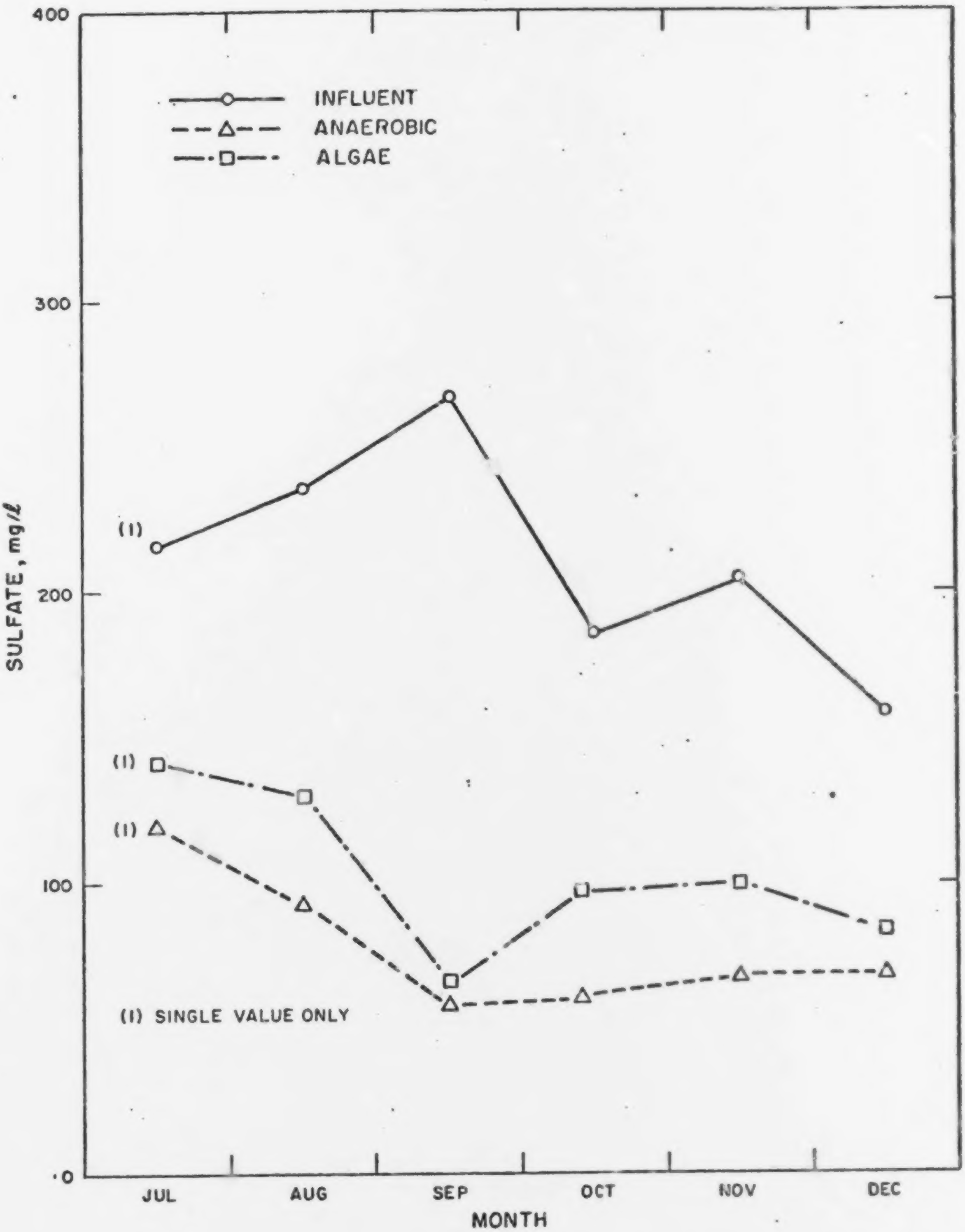


FIGURE 11. MONTHLY MEAN VALUES FOR SULFATE AS A FUNCTION OF POND AND MONTH

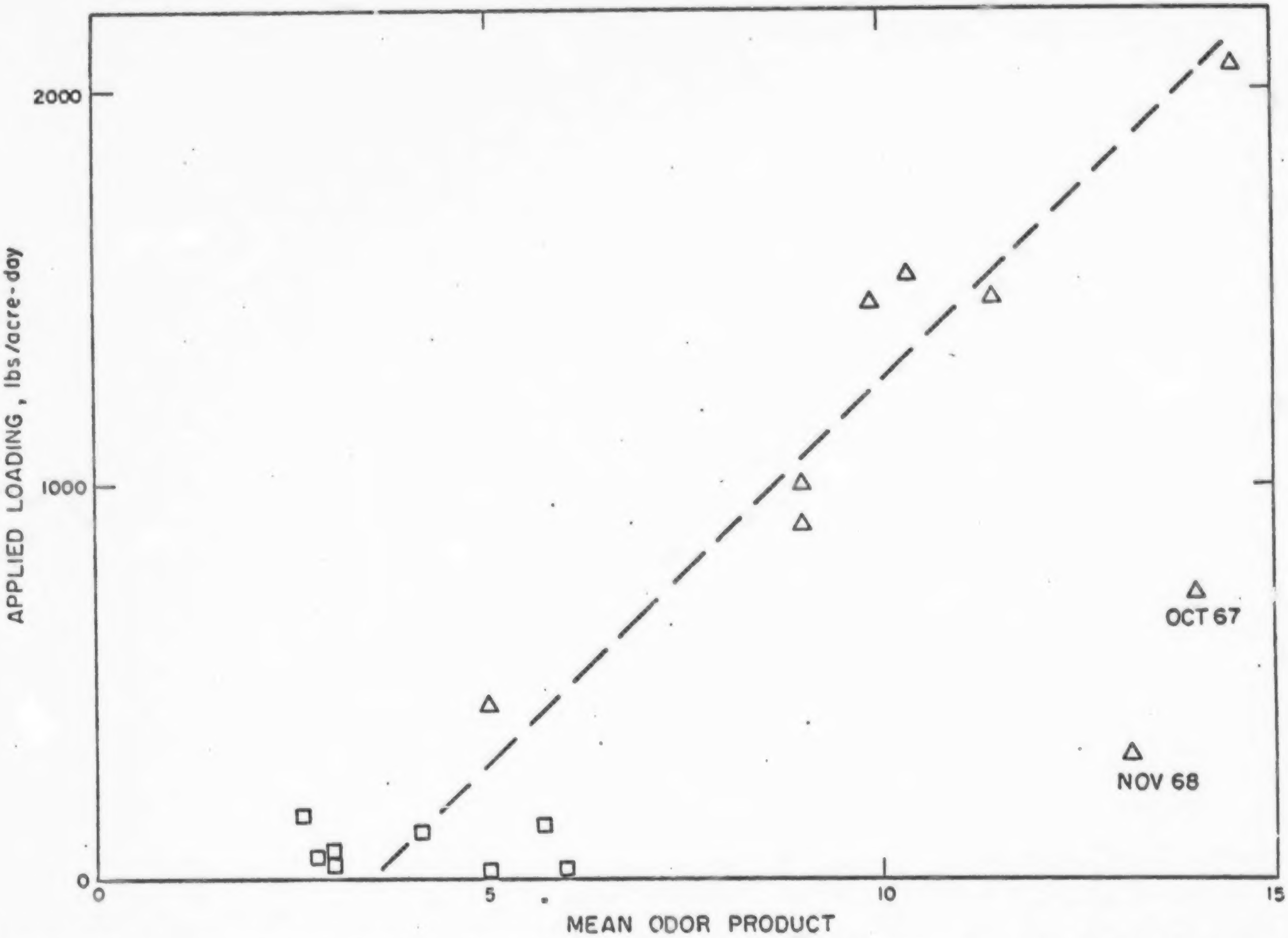


FIGURE 12. MONTHLY MEAN ORGANOLEPTIC ODOR PRODUCT AS A FUNCTION OF APPLIED AREAL LOADING

product and loading, the approximate relationship being that $OP = 3.5 + .0053L$(2) in which OP is the odor product and L is the BOD loading in lbs/day/acre. As an example, for a BOD loading of 1,000 lbs/day/acre, the indicated odor product would be 8.8.

Monthly mean value for the unfiltered COD of the waste is shown in Figure 13, and for filtered COD in Figure 14. It is evident from the figures that in spite of the fact that the filtered COD varied from 500 to almost 2,000 mg/l, the effluent COD remained relatively low. The indication is that as the season progressed, while a greater and greater fraction of the organic load was converted from insoluble to soluble form; the insoluble form increased in the ponds, probably reflecting deterioration of the beets with aging in the Fall and the growth of increased amounts of microbial material in the ponds.

Nitrogen in the waste similarly increased. A summary of monthly mean nitrogen values is shown in Table 5. Of interest is the fact that nitrate removal in the anaerobic pond was consistently high, whereas ammonia nitrogen removal declined with temperature and an increased fraction of the nitrogen became incorporated in organic matter in the anaerobic and algae ponds as temperature decreased. The indication is that the nitrogen removal mechanisms in the anaerobic pond are primarily microbial in nature.

Nutrient relationships for carbon, nitrogen, and phosphate in the system are shown in Table 6. The evidence is that carbon/nitrogen ratios were too high for ideal microbial growth during most of the time, and that nitrogen as well as phosphate addition would have benefitted the system. The evidence is, however, that nutrients should not be added to the anaerobic pond, since both nitrate and phosphate are apparently to some extent reduced along with sulfate. The corollary is that any nutrient addition should be made in the aerobic pond where they would become incorporated in algal cells and through recirculation returned to the anaerobic pond in the form of organic nitrogen.

The quantity of algae in the ponding system was estimated on the basis of centrifuged packed solids, and the results of these determinations are shown in Figure 15. All solids data is shown in Table 7. It is apparent from Figure 15 that the maximum bloom of about 280 mg/l of algae occurred in the algae pond during September, after which it declined. On the other hand, the concentrations of algae in the anaerobic pond steadily increased, possibly reflecting decreased breakdown in the anaerobic pond at lower temperatures or some concentration phenomenon. During September and October there was a serious depletion in algae concentration due to invasions of the algae pond by rotifera and daphnia. These incursions caused a depletion of dissolved oxygen in the system, and in one case apparently triggered a bloom of purple sulfur bacteria which in September briefly replaced algae as the principal photosynthetic organism in the system.

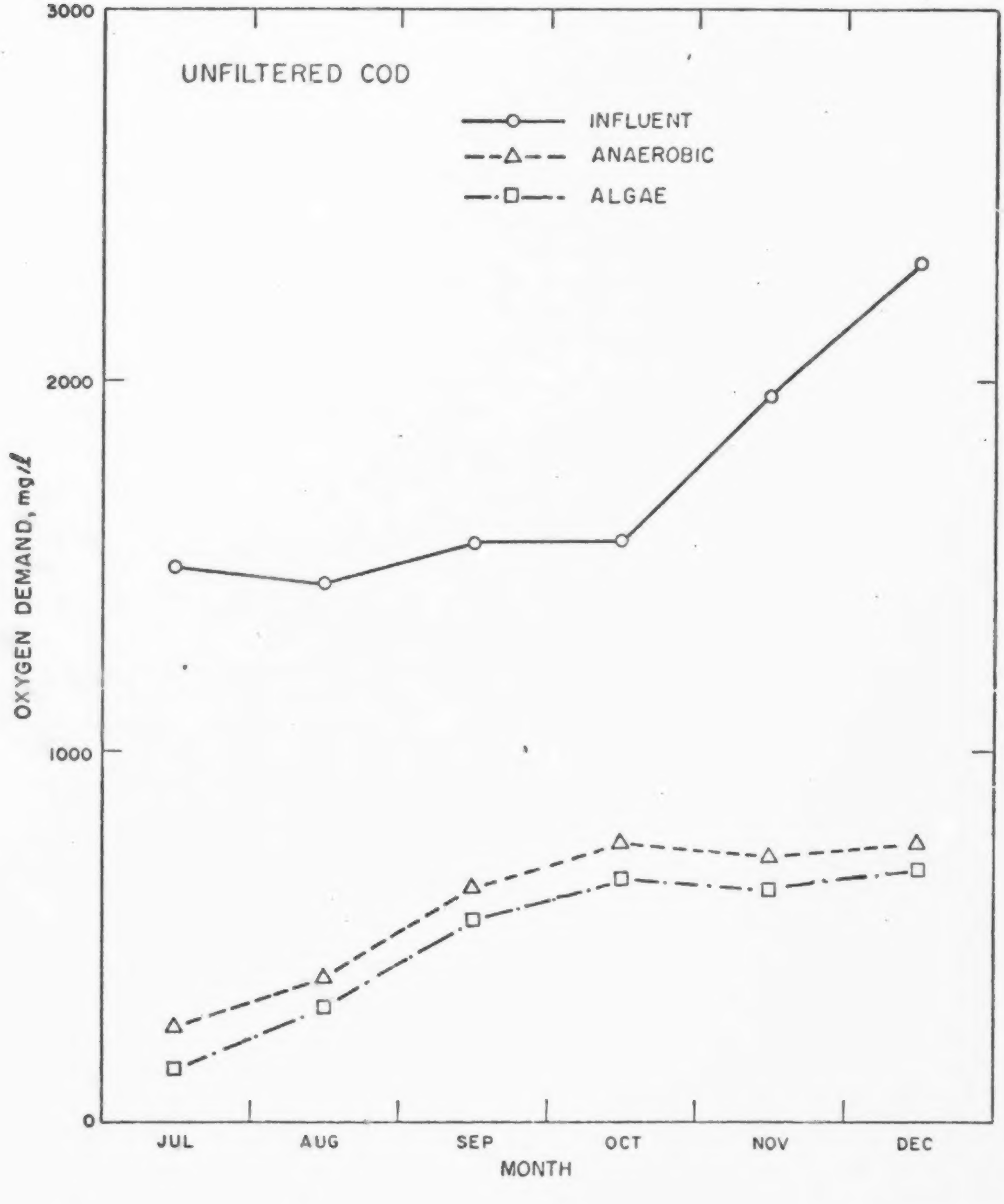


FIGURE 13. MONTHLY MEAN VALUES FOR UNFILTERED COD AS A FUNCTION OF POND AND MONTH

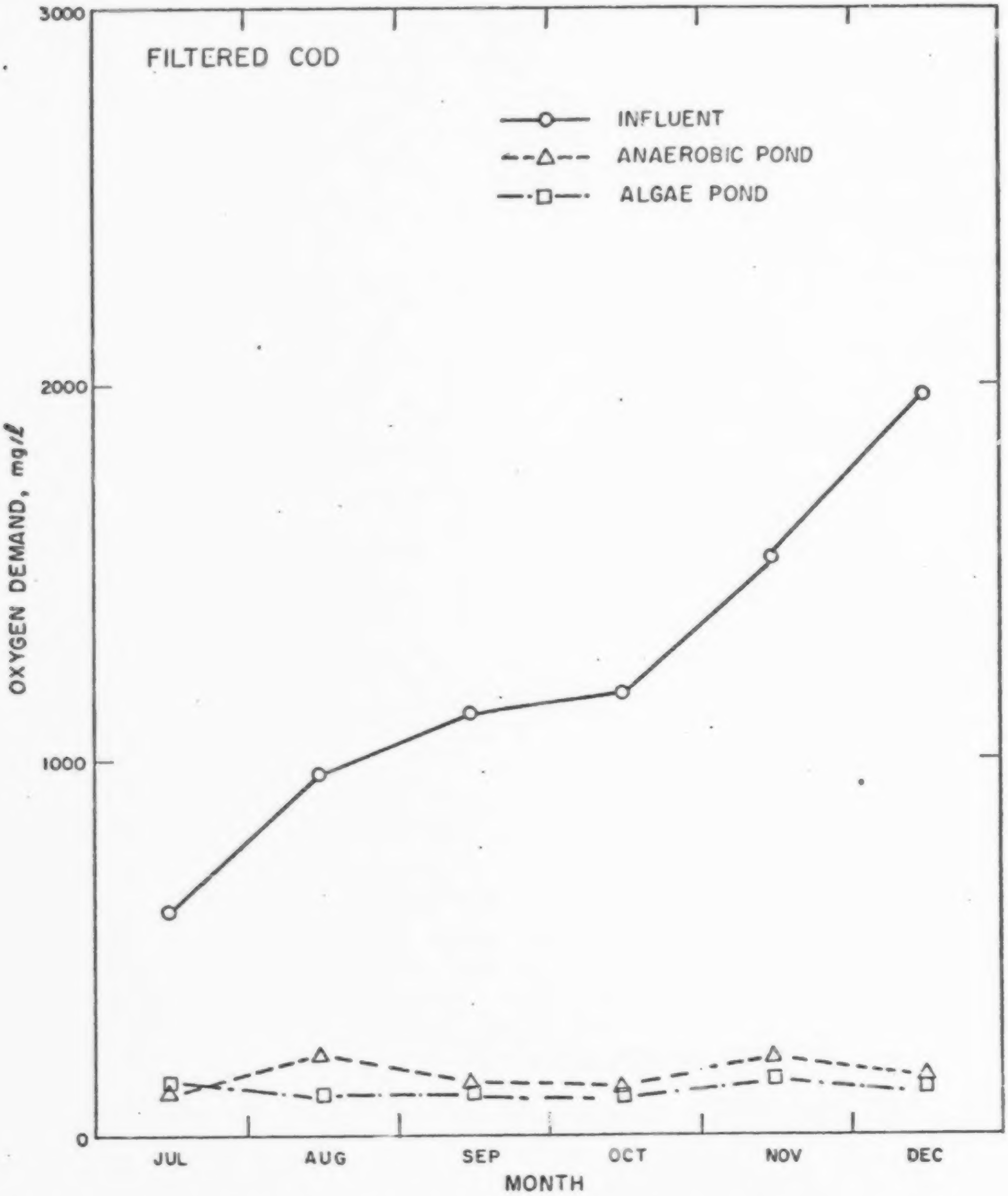


FIGURE 14. MONTHLY MEAN VALUES FOR FILTERED COD AS A FUNCTION OF POND AND MONTH

TABLE 5

Summary of Monthly Mean Nitrogen Values as a Function of Species, Pond and Month - All Values Mg Per Liter as N

Month	Sample	NO_3^-	NH_4^+	$NO_3^- + NH_4^+$	Total N	Diff[1]
Jul[2]	In	2.3	2.0	4.30	5.25	0.95
	An	0.2	0.2	0.40	1.40	1.00
	Al	0.2	0.1	0.30	0.60	0.30
Aug	In	2.97	1.64	4.61	5.60	0.99
	An	0.36	1.18	1.54	2.60	1.06
	Al	0.42	0.68	1.10	1.81	0.71
Sep	In	1.45	1.17	2.62	4.85	2.23
	An	0.42	0.58	1.00	3.78	2.78
	Al	0.40	0.30	0.70	4.23	3.53
Oct	In	3.20	1.38	4.58	4.77	0.19
	An	0.51	0.79	1.30	4.22	2.92
	Al	0.50	0.54	1.04	4.30	3.26
Nov	In	4.31	2.76	7.07	9.28	2.21
	An	0.48	1.63	2.11	6.21	4.10
	Al	0.55	1.31	1.86	5.44	3.58
Dec	In	3.14	1.54	4.68	7.53	2.85
	An	0.45	1.30	1.75	5.77	4.02
	Al	0.67	1.10	1.77	6.25	4.48

[1] The difference is assumed to be organic N plus nitrite N, the latter usually being negligible in magnitude.

[2] July values are singles or duplicates only, all others are means of 10 - 20 values.

TABLE 6

Nutrient Relationships

Month	Sample	Filt COD mg/l	C[1] mg/l	N[2] mg/l	C/N	P[3] mg/l
Aug	In	961	404	5.6	72	1.5
	An	217	91	2.6	35	13.9
	Al	112	47	1.8	26	7.3
Sep	In	1128	474	4.8	99	0.78
	An	144	60	3.8	16	2.04
	Al	116	49	4.2	12	1.57
Oct	In	1180	495	4.8	103	0.79
	An	137	57	4.2	14	1.25
	Al	104	44	4.3	10	0.54
Nov	In	1541	647	9.3	70	1.53
	An	209	88	6.2	14	1.43
	Al	150	63	5.4	12	9.30
Dec	In	1969	827	7.5	110	0.57
	An	165	69	5.8	12	0.43
	Al	130	55	6.2	9	7.10

[1] 0.42 x Filt COD

[2] Total Nitrogen in unfiltered samples. No extra nitrogen was added during the course of these experiments.

[3] P was added at the approximate average rate of 5 mg/liter. Because of poor flow control, phosphorus levels were sporadic but in excess of normal requirements.

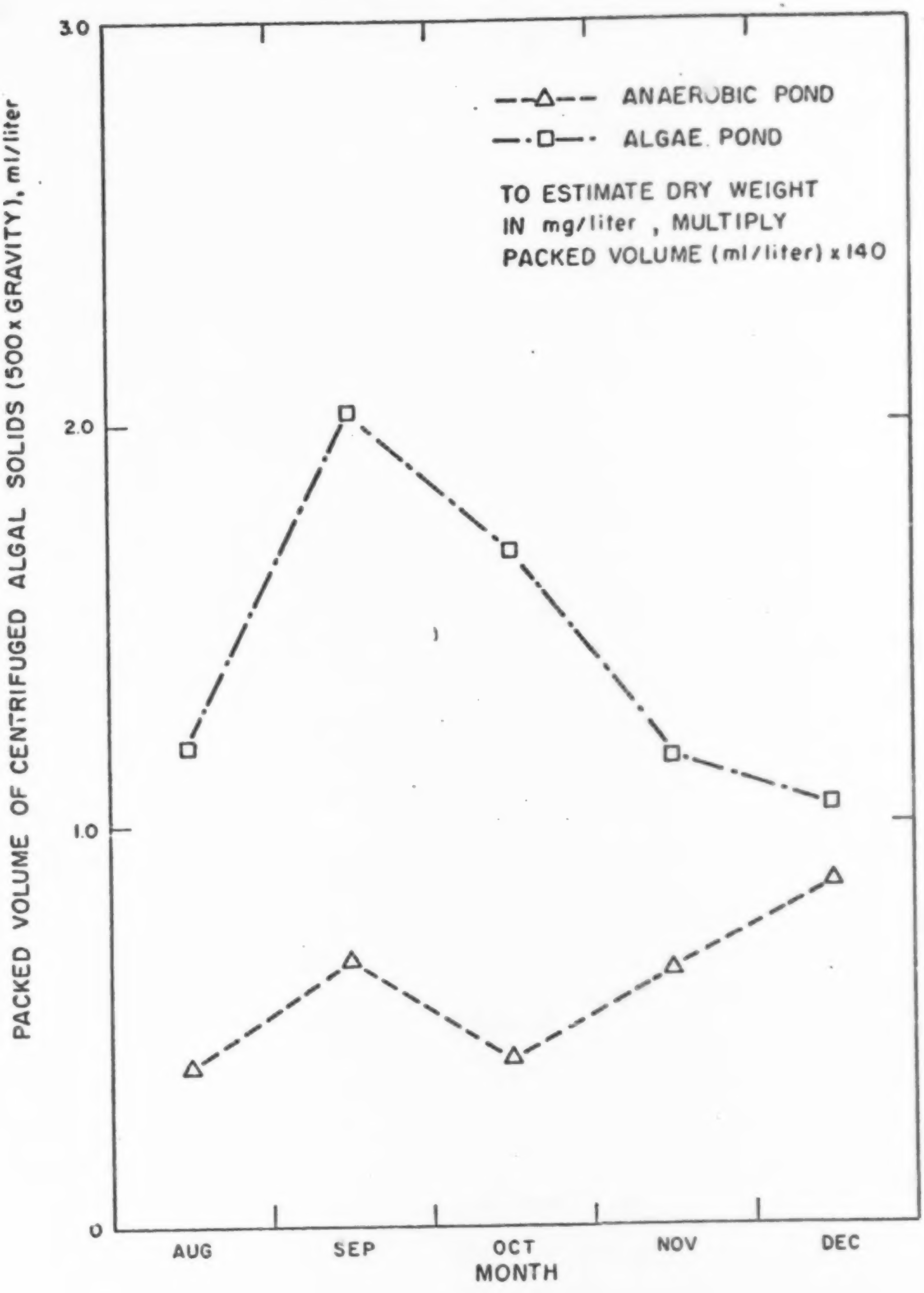


FIGURE 15. MONTHLY MEAN PACKED VOLUME OF CENTRIFUGED ALGAL SOLIDS AS A FUNCTION OF MONTH AND POND

TABLE 7

Summary of Solids Data

Monthly Mean Dissolved Solids mg Per Liter

Month	Volatile			Ash			Total		
	In	An	Al	In	An	Al	In	An	Al
Jul	975	333	268	1039	1164	1149	2014	1497	1417
Aug	1358	520	391	1128	1002	1099	2486	1522	1490
Sep	1150	477	441	1118	922	978	2268	1399	1419
Oct	1250	608	528	946	831	930	2196	1439	1458
Nov	1513	557	507	1215	898	935	2728	1455	1442
Dec	2142	606	523	1129	884	954	3271	1490	1477

Monthly Mean Suspended Solids mg Per Liter

Month	Volatile			Ash			Total		
	In	An	Al	In	An	Al	In	An	Al
Jul	105	84	94	148	19	20	253	103	114
Aug	241	128	156	239	25	27	480	153	183
Sep	378	376	374	465	82	88	843	458	462
Oct	199	452	414	447	155	131	646	607	545
Nov	199	413	369	212	79	75	411	492	444
Dec	327	492	395	472	152	98	799	644	493

Monthly Mean Total Solids mg Per Liter

Month	Volatile			Ash			Total		
	In	An	Al	In	An	Al	In	An	Al
Jul	1080	417	362	1187	1183	1169	2267	1600	1531
Aug	1599	648	547	1367	1027	1126	2966	1675	1673
Sep	1528	853	815	1583	1004	1066	3111	1857	1881
Oct	1449	1060	942	1393	986	1061	2842	2046	2003
Nov	1712	970	876	1427	977	1010	3139	1947	1886
Dec	2469	1098	918	1611	1036	1052	4070	2134	1970

Results of the study on gas production are presented in Figure 16. As the Figure shows, no gas production occurred below 13.5°C, and some form of inhibition of gas production occurred above 17°C. The nature of this inhibition is unknown, but it obviously must have severely influenced the nature of BOD removal and odor production in the anerobic pond.

DISCUSSION

The results of the studies reported herein show very clearly the extensive variation in waste strength, ph, and nutritional characteristics of beet sugar factory wastes. The seasonal variation in waste strength are so large that it would be impossible to design an effective unbuffered, short detention waste treatment system for steady-state or average conditions. The degree of variability is apparent when one examines the unfiltered COD data (reference 4 Appendix 3A) in which values vary from 550 mg/l in August to 3643 mg/l in November, and 3380 mg/l in December; and when one considers the influent pH values shown in Figure 9 which vary from 5.7 to 11.6.

No short-detention period biological system lacking in buffer capacity could withstand sudden shifts in nutrient and pH of the magnitude found without violent upsets or complete failure in essential microbial growth. High-rate ponds could tolerate the changes in pH, but could not tolerate the changes in loading. Activated sludge units could not tolerate either the change in pH or the change in loading. Trickling filter units could perhaps tolerate the variable loading but could not tolerate the variable pH. Thus, activated sludge units, high-rate ponds, and trickling filters if considered in the design of primary units of systems for factory waste would have to be designed for that loading which could not be exceeded at least 95 percent of the time. They would have to be continuously monitored and protected from changes in pH. Design criteria such as these would make such treatment extremely expensive. The obvious corollary to these statements is that a massive primary buffer system is vital to any successful and economical biological treatment of beet sugar factory waste. In considering the design characteristics of a buffering system, the anaerobic pond is an obvious choice because its simple earthwork construction, large size and relatively long detention period will, according to our evidence, buffer almost any extreme variation in pH which might occur in a factory effluent and would dampen changes in BOD. At the same time it would be relatively inexpensive.

In view of the necessity of a buffer pond, it is fortunate that in addition to acting as a buffer, a substantial degree of waste treatment is attained in an anerobic pond. It was found during the course of these investigations that in the anerobic pond BOD removal was directly proportional to BOD loading in the range of 500 to 2,000 lbs of BOD/day/acre. At loadings above 2,000 lbs, removal efficiency is believed to decline. The removals as found are related to loading approximately as follows:

$$R = 0.8\ L \qquad (3)$$

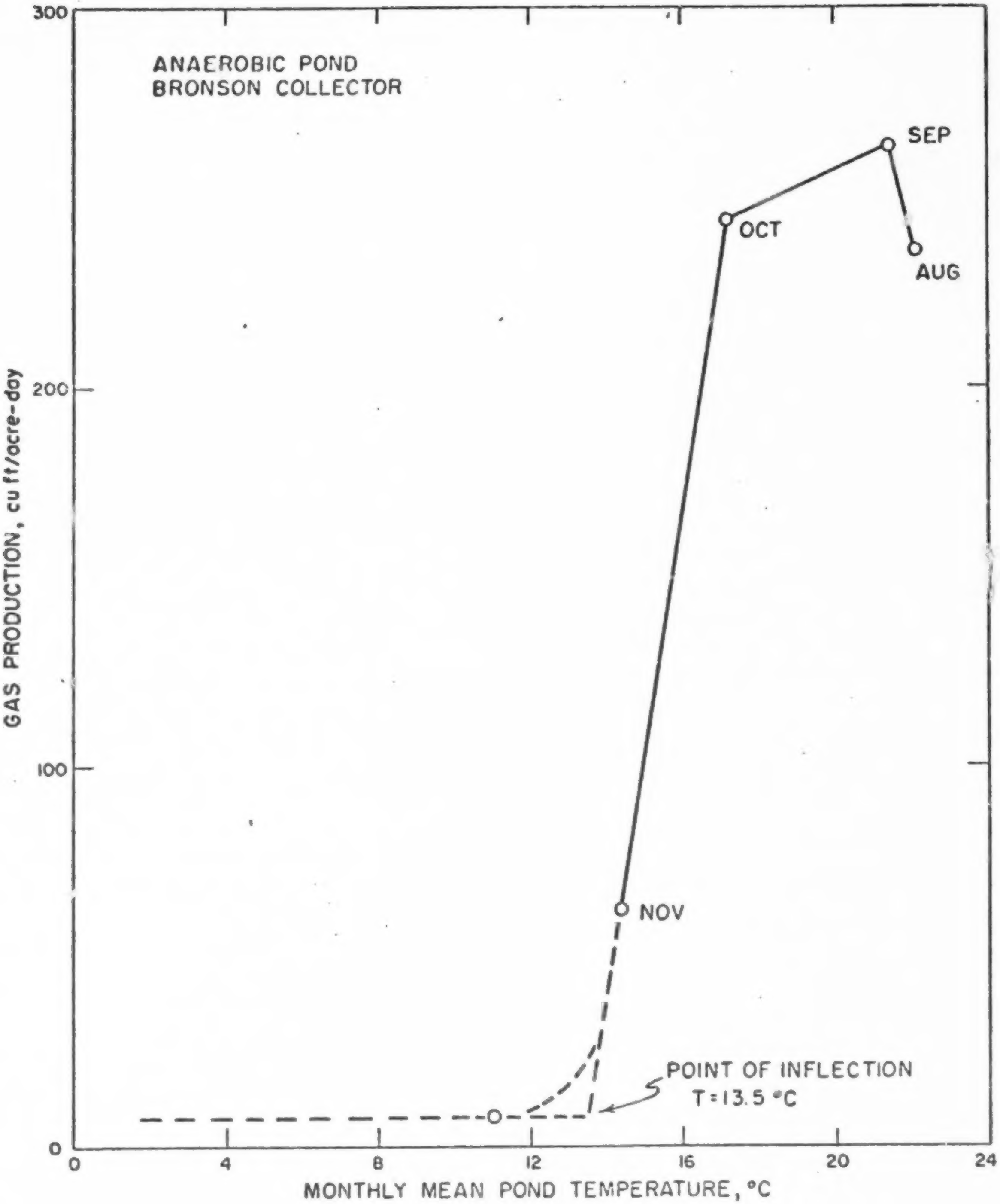


FIGURE 16. RELATIONSHIP BETWEEN GAS PRODUCTION AND TEMPERATURE FOR VARIOUS MONTHS

in which L is the BOD load between 500 and 2,000 lbs/day/acre and R is the BOD removed. Of course, both R and L should be expressed in the same units. Thus, it appears that an anerobic pond loaded at 1,000 lbs/day/acre will produce an effluent containing 200 lbs of BOD/day/acre and one loaded at 2,000 lbs/day/acre will produce an effluent having 400 lbs of BOD/day/acre. If BOD loading were the only criterion of performance, the obvious choice of recommended design loading would be 2,000 lbs/day/acre. It is an unfortunate fact that when the study pond received BOD loadings as high as 2,000 lbs/day/acre, it was continuously malodorous; hence some criterion other than Equation 3 is required on which to base a decision regarding an upper limit for anaerobic pond loading. Two main criteria seem to be available: odor level and acceptable discharge BOD.

Inasmuch as odor is one of the most urgent problems, odor level will be discussed first. In the case of the anerobic pond, the data accumulated during this study were not sufficiently refined for a final conclusion; but one is left with the general impression that for normal beet waste, an odor product of lower than 8 to 10 may be barely acceptable. An odor product much above 10 is definitely unacceptable because it is always accompanied by sulfide concentrations which are always detectable. An allowable odor product of 10 would imply very little carrying power for the odors; or in air, odors of such intensity would be quickly diluted to subliminal levels as a function of distance from the ponding site. It seems quite certain that odor products of 8 or less would be acceptable for anaerobic ponds because these levels were sometimes reported for the aerobic pond, which was never described as objectionable in pond-site observations.

In the plot of odor product vs loading, there was a straight-line relationship with two observed exceptions--the October 1967 data and the November 1968 data. These data come from periods when there were serious interruptions in flow, and consequently rapid changes in the environment. Total nitrogen concentrations were also high during these periods, possibly due to the discharge of Steffens waste. Steffens waste is, of course, notorious for its ability to produce vile odors when impounded, and "Steffens waste spills" are always accompanied by sudden increases in odor in ponding systems(8). There was, however, no reported incidence of a "spill" and no report that Steffens waste had been bled into the effluent. Thus, it can only be concluded at this time that a load of 1,000 lbs of BOD/day/acre may be acceptable in an anerobic pond when mechanical surface aeration is applied to the extent of meeting one-third of the applied BOD, and when the effluent is discharged into a functional aerobic or algae pond from which there is a recycle of about 1 Q and in which algae are growing and producing oxygen.

With regard to acceptable discharge BOD, effluents from the anaerobic pond varied from 129 mg/l at a load of 500 lbs/day/acre to in excess of 400 mg/l at a load of 2,000 lbs/day/acre. Water of this quality would be useless and its discharge illegal without extensive additional treatment.

The additional treatment studied involved both facultative and algae ponding. At BOD levels ranging from 50 to 200 lbs/day/acre as noted previously, odor products in the systems studied tended to be 6 or less and objectionable odors at the pond side were minimal.

With regard to the application of BOD criteria to the facultative pond and algae pond, an examination of the available data is best aided by plotting mean final effluent BOD as a function of mean BOD loading. Such a plot is shown in Figure 17. As is evident from the Figure, the BOD of unfiltered effluents was not affected by loadings up to 100 lbs/day/acre while the BOD of filtered effluents was not affected by loadings up to 180 lbs/day/acre, but the unfiltered BOD both from the facultative pond in 1967 and the algae pond in 1968 would not be acceptable in the environment under the currently proposed water quality standards(9).

It is important to note that decreased BOD loadings below 100 lbs/day/acre did not appear to influence the effluent BOD, probably because most of the BOD involved in these samples was of a suspended nature, either in the form of colloidal sulfides, algae cells, or of bacterial cells. This was true because the pond was continuously mechanically mixed and samples were drawn directly from the mixing system. The suspended nature of the BOD is demonstrated by the fact that the BOD of the algae pond effluent was reduced from levels of 150 to 190 mg/l to 10 to 13 mg/l by filtration. In view of these relationships, it is apparent that the poor BOD removals attained in the algae pond were due to removable BOD. Therefore, had the removal been effected, greater efficiencies would have been attained.

Merely decreasing the BOD loading below 100 lbs/day/acre did nothing to improve effluent quality. On the other hand, filtration improved quality dramatically even at loadings of 180 lbs/day/acre. An examination of suspended solids data shows that effluent suspended solids often exceeded a concentration of 500 mg/l with over 75 percent volatile matter. Thus, apparently an improved unfiltered effluent could not be attained by reduced loading. It should be noted, however, that in the case of the algae pond, loadings between 100 and 180 lbs/day/acre yielded effluents which when unfiltered had BOD levels between 80 and 190 mg/l respectively. Thus, while a loading of 100 lbs/day/acre was associated with unsuitable effluents, higher loadings produced effluents substantially more unsuitable. The apparent conclusion is that aerated-anaerobic ponding followed by either facultative or algae ponding without further treatment did not produce an effluent suitable for discharge regardless of the degree to which loading is decreased. One is then, confronted with only two clear alternatives: 1) to use facultative secondary ponds loaded at 100 lbs/day/acre or less and to dispose of the final effluent on land owned by the Factory from which there is no discharge; or 2) to use a more intensive form of secondary ponding and to remove suspended solids from final effluents prior to discharge by filtration or some other method of separation which will remove the fine suspended solids which contribute most of the effluent BOD.

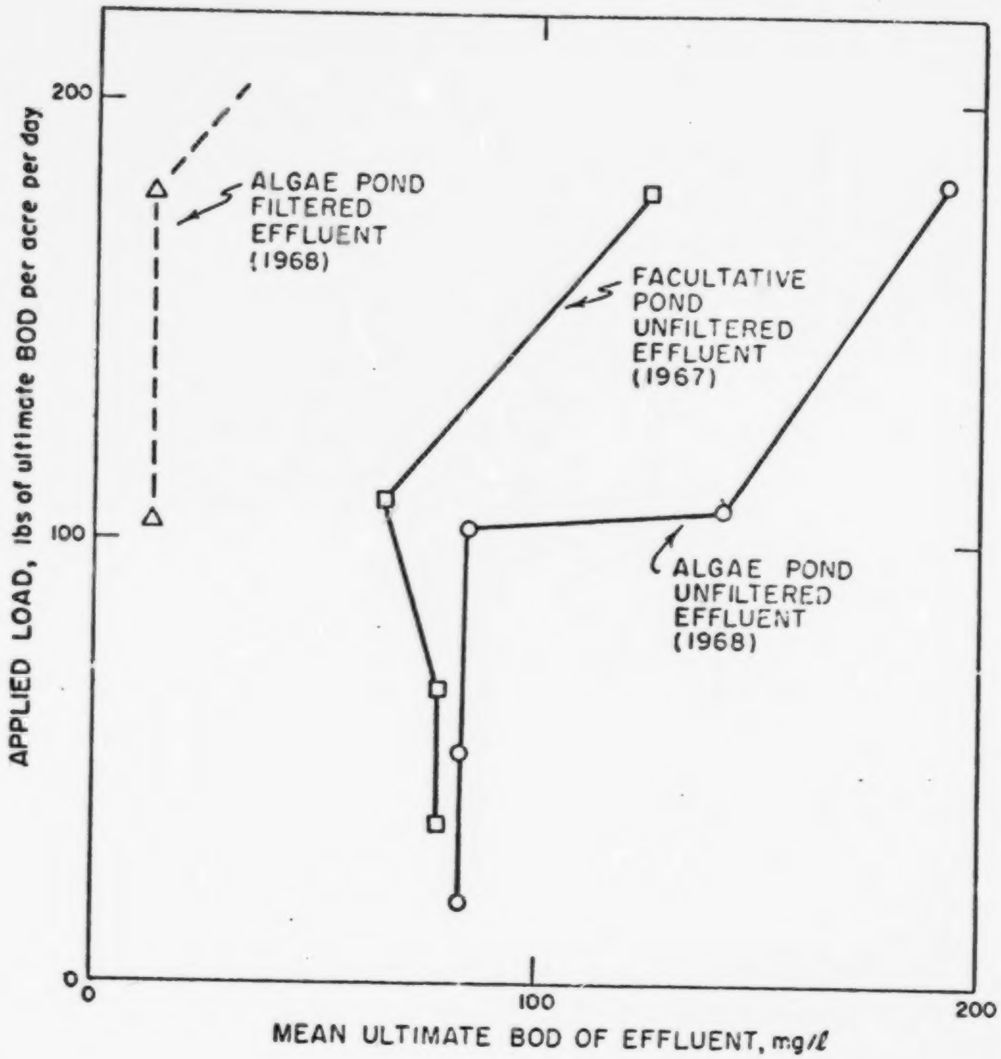


FIGURE 17. MONTHLY MEAN BOD OF ALGAE OR FACULTATIVE PONDS AS A FUNCTION OF BOD AND FILTRATION

Intensive secondary ponding could involve the use of mixed algae ponds of the type studied, or an even more intensive form of algae production. For example, where climate permitted, the algae pond could be optimized for photosynthetic oxygenation with an average production of about 200 lbs of oxygen and 120 lbs of algae/day/acre. Under these conditions, it is conceivable that the value of the filtered solids could pay for the cost of filtration. However, this would require much more study. Allowable loading would then be about 200 lbs/day/acre, and following separation the discharge would meet rigorous quality standards. One may then logically say, "Why discharge such high quality water particularly in water-short areas?" If the quality of a filtered discharge is as high as indicated in Figure 17, reuse in the factory by recycle is a worthwhile consideration whenever filtration is used. Obviously the less new water brought into a factory the less it will have to discharge. On the other hand, because of the high water content of beets, it seems inevitable that factories will always be forced to discharge or otherwise dispose of large amounts of excess water regardless of recovery practice.

Based on the criteria of 80 percent BOD removal in a primary anaerobic pond and a loading of 200 lbs BOD/day/acre in an algae pond, one can explore the areal requirements for treatment in an idealized anaerobic-algae system. To have a basis for calculation, a 4.5-K ton factory discharging 36,000 lbs of BOD per day is assumed. It is also assumed that excessive odors will occur when the aerated-anaerobic pond loading exceeds 1000 lbs of BOD/day/acre. If a load of 500 lbs of BOD were applied to the anaerobic pond, the area of anaerobic pond would be 72 acres, the discharge would be 100 lbs/day/acre or 7,200 lbs, and 36 acres of algae pond would be required for an aggregate area of 108 acres. If a load of 1,000 lbs/acre is applied to the anaerobic pond, the total loading of 36,000 lbs will require 36 acres. The anaerobic pond effluent will contain 7,200 lbs of BOD and therefore will require 36 acres of algae pond. The aggregate area in this second case would be 72 acres. If a load of 2,000 lbs of BOD/acre were used, 18 acres of anaerobic pond would be required for anaerobic treatment, but odors would be severe and a stronger waste would be discharged to the algae pond. Although according to Equation 2 the effluent BOD would be 7,200 lbs, and would require 36 acres of algae pond, in reality because of bacterial and sulfide turbidity, an area larger than 36 acres--say 40 acres--probably would be required if the effluent were to be fully oxidized. Moreover strong odors would occur.

A plot of these relationships is presented in Figure 18. From the Figure, it becomes evident that with the assumptions described, the minimum area required for odor-free treatment of factory waste from a 4.5 K ton factory by an aerated anaerobic-algae system would be about 72 acres. Higher loadings would be accompanied by severe odors and, as indicated by the dotted portion of the top curve, would require more algae ponds for aeration. Lower loadings would, of course, require more area, the area increasing as the areal loading is decreased.

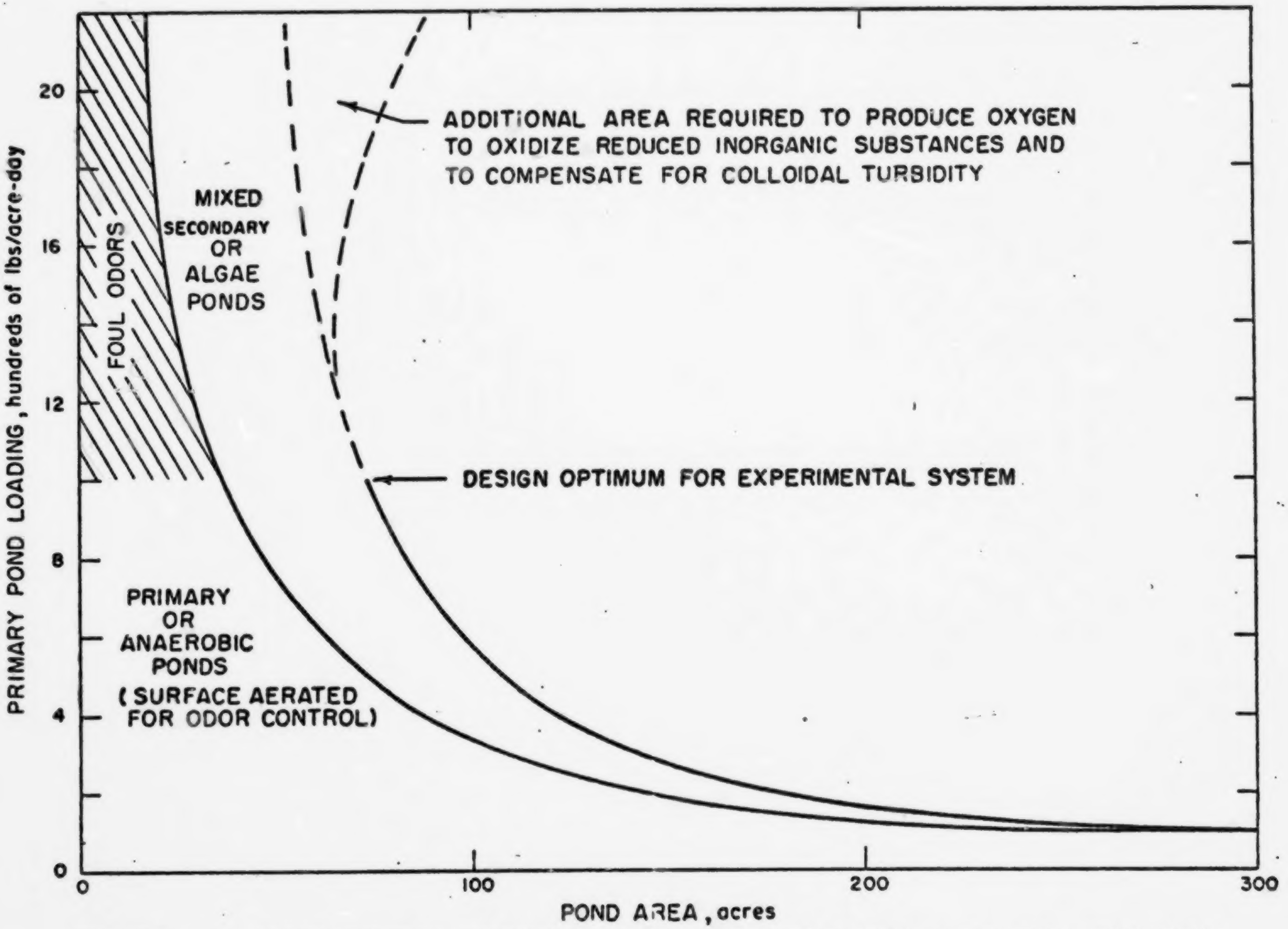


FIGURE 18. MAIN WASTE PONDING AREA REQUIRED FOR 4.5 K-TON FACTORY

As an alternative to using facultative or algae ponding as the secondary system, one should consider the alternatives of more intensive aeration of primary ponds or the use of aerated secondary ponds. The possibility of applying additional surface aeration in an anaerobic pond to prevent odors and to permit higher areal loadings and decreased pond surface area is worthy of consideration, and was to some extent examined experimentally. In the study with a 5 hp floating surface aerator, it was found that as long as the dissolved oxygen remained zero, oxygen entered the pond at the rate of 307 lbs/day due to the 5 hp aerator. Odor emission, however, appeared to be a function of the amount of unoxidized material remaining, rather than a function of the rate of aeration. Thus, if one were to go from a loading of 1,000 lbs/day/acre to a double loading of 2,000 lbs/day/acre, control of odor probably could not be attained by aerating at twice the 307 lbs/day/acre, i.e., 614 lbs/day/acre. Instead aeration would have to be at a rate of 1000 + 307 lbs or 1,307 lbs/day/acre. Thus, it is believed that to double loadings in the system studied, aeration would have to be increased fourfold to prevent odors. The savings in area would thus have to be evaluated in terms of the cost of one 20 hp aerator operating continuously for each acre of secondary pond replaced. Thus, the possibility of decreasing area by going to loadings higher than 1,000 lbs/day/acre is not as attractive as it might at first seem.

With regard to replacement of secondary facultative or algae ponds with aerated secondary ponds, it will be assumed that the mechanically induced reaeration rates obtained in oxygen-free ponds do not apply and that the dissolved oxygen level for discharged or recovered water should be about 4 mg/l. Under such conditions, according to the manufacturers brochure(7), a surface aerator provides 1.8 lbs of O_2 per hp-hr. At this rate, each 5 hp aerator will contribute 220 lbs of O_2 per day. This is approximately the amount of oxygen contributed by one acre of high-rate pond. By itself, a 5 hp aerator would probably be less costly than one acre of pond, but inasmuch as wastewater storage for reuse or disposal may be an essential part of any practical system, a substantial pond area may be required anyway, and all of the pond costs therefore need not be allocated against the aeration process.

Aeration due to flow mixing also is worthy of consideration as a source of supplemental aeration. This form of aeration is often referred to as eddy diffusion aeration because it is dependent on renewal of the surface resulting from eddies generated as the water moves past small discontinuities at the pond bottom. A pond four-feet deep with the liquid moving around a closed circuit at a velocity of one foot per second and containing no free dissolved oxygen will absorb about 100 lbs of oxygen/day/acre through surface reaeration. Although this amount of oxygen is small compared with that attainable through mechanical surface aeration, it is a method which is compatible with photosynthetic oxygenation. If the liquid contains growing algae and essential nutrients, the algae may produce over 200 lbs of oxygen/day/acre through photosynthesis, and the dissolved oxygen level will always be positive and frequently near saturation. Oxygen produced photosynthetically, of course, does not depend upon an oxygen deficit for input; and hence, never is accompanied by vile odors. Odors could result if the pond were so severely overloaded on a sustained basis that algae were unable to grow. However, if algae either fail to grow for one reason or another or are killed by toxins or predators, eddy diffusion aeration in the flow system will provide for the absorption of sufficient oxygen by the pond to keep it from producing vile odors of high intensity, providing the loading does not exceed 200 lbs/day/acre. Thus, flow mixing is an excellent backup for photosynthetic oxygenation; but it is not as efficient an aeration system as is mechanical surface aeration.

Provision for any form of biological treatment requires in addition to a mild and stable environment adequate nutritional conditions. Flume water usually contains about 400 mg/l of carbon as C, about 15 mg/l of available nitrogen as N, and about 3 mg/l of soluble phosphate as P. Rapidly growing bacteria are about 40 percent carbon as C, 10 percent N as N, and 1.5 percent phosphorus as P, and rapidly growing microalgae are about 55 percent carbon as C, 8 percent nitrogen as N, and 1 percent phosphorus as P. Based on these percentages, flume water contains enough carbon to support 725 mg/l of algae, enough nitrogen to support 188 mg/l of algae, and enough phosphorus to support 300 mg/l of algae. It is clear that compared with carbon, there is a deficit in both nitrogen and phosphorus, and that 725/188 x 15 or about 88 mg/l of N and 725/300 x 3 or about 7.25 mg/l of P would be required to permit incorporation of all of the organic carbon into algae. Thus, 73 mg/l of N and 4.25 mg/l of P would have to be added. A less expensive alternative would be to remove carbon by processes other than by photosynthesis, and thereby decrease the carbon to a point at which it is in balance with the nitrogen and phosphorus for algae growth. By so doing, it would not be necessary to provide supplementary nitrogen and phosphorus.

Several processes observed in the anaerobic pond during this study are accompanied by loss of considerable carbon dioxide to the atmosphere. This is probably especially true in the case of mechanically aerated ponds. For example, the satisfaction of 307 lbs of BOD/day/acre by aeration led to the production of 450 lbs of CO_2 per acre. Thus, probably 122 lbs of carbon/day/acre was lost to the air. This alone would constitute a loss of 222 lbs of carbonaceous AGP. Following this line of reasoning, if two-thirds of the BOD had been met by aeration, sufficient carbon would have been lost to permit the balance to be incorporated in algae with no need to add nitrogen or phosphorus.

Methane fermentation also is a potential method for decreasing the carbon content of the waste. As noted earlier, methane fermentaion in the system was extemely low, and did not establish itself appreciably in spite of the presence of large amounts of carbon, highly anaerobic conditions, adequate temperatures, and sustained periods of inundation.

Under the warmest temperatures encountered in the study, 250 ft^3 of gas were emitted from the bottom of the anaerobic pond. This gas probably contained about 50 percent methane, of which 75 percent is carbon. Thus only about 4 lbs of carbon were lost daily by fermentation. If methane production rates equal to those in domestic sewage ponds had been attained, as much as 200 lbs/acre of carbon would have been lost daily in the form of methane. However, this did not occur in the system. As to why it did not occur, it is possible that methane bacteria found it difficult to survive in a pond in which surface aeration was in progress. However, even before the aerator was installed, there was a dearth of fermentation. Thus, further studies would be required to substantiate aeration interference. Another hypothesis advanced for poor fermentation is the excess of H_2S or sulfides in the system due to vigorous sulfate reduction in the anaerobic pond. Sulfide is known to be toxic to methane bacteria even in moderate concentrations. Thus, carbon elimination by methane fermentation could have been inhibited by this mechanism.

In order to continue with the discussion of carbon, nitrogen, and phosphorus ratio and the need for nutrient supplementation, it is necessary to digress slightly to explore sulfate reduction in some detail, since this is also a potentially significant way in which carbon may be lost.

The overall reaction involved in production of H_2S from sulfate using organic matter as an energy source is approximately:

$$H_2SO_4 + 2CH_2O \xrightarrow[\text{Organics}]{\text{Bacteria}} H_2S + 2CO_2 + H_2O \tag{4}$$

According to the data on sulfate reduction shown in Figure 11, as much as 208 mg/l (average about 140 mg/l) of sulfate was reduced in the anaerobic pond during the five-month period of observation. Based on the stoichiochemistry of equation (4), the reduction of 140 mg/l of sulfate would have involved the oxidation of 88 mg/l of organic matter and the production of 50 mg/l of H_2S and 128 mg/l of CO_2 or 35 mg/l of carbon. A substantial fraction of this CO_2 was doubtlessly incorporated in the alkalinity of the water in the anaerobic pond.

One may question why, that although 50 mg/l of H_2S were produced, a maximum of only 5-6 mg/l of HS^- were recovered. This imbalance may be explained by the supposition that as soon as HS^- was produced, it could have reacted in several ways. It could have reacted with magnesium or other metals in the system to produce insoluble metal sulfides which of course were not measured in the dissolved sulfide determination; it could have been emitted into the air by action of the aerator; or it could have been utilized by sulfur bacteria. Emission into the air was evidenced by the presence of sulfide odors about the anaerobic pond. However, the magnitude of emission must have been small because of the pH of 7.5 to 8, (a level almost always found in the anaerobic pond) most of the sulfide would be present as the HS^- species rather than as H_2S.

Inasmuch as there is no H_2S normally in the air, the reaction involved in the emission of H_2S occurs spontaneously whenever dissolved H_2S exists in solution. The quantity remining in solution is mainly a function of pH. The reaction is:

$$H^+ + HS^- \underset{Basic}{\overset{Acid}{\rightleftarrows}} H_2S\uparrow \qquad (5)$$

At pH 4 practically all of the material is in the H_2S or gaseous form and emission rates are high. At pH 6, half is in the gaseous form and half in the ionic HS^- form; and at pH 7.5, about 90 percent is in the ionic form and 10 percent in gaseous form and emission rates are low. At pH 9.5, almost all material is in the ionic form and there is no emission of H_2S. Thus, in view of the pH levels in the anaerobic pond (Figure 9), the possibility is slight that all H_2S would have been emitted due to aeration during August, September, October, and November when the pH was higher. Yet, a substantial fraction could have been lost that way during December when the pH was low. The curves in Figure 11 give evidence that some sulfides were probably carried over into the algae pond as a reduced complex which later was oxidized to sulfate. This is evidenced by the fact that the sulfate concentration in the algae pond was consistently greater than it was in the anaerobic pond.

With regard to the loss of sulfide to sulfur bacteria, according to the data collected there were numerous sulfur bacteria in the pond from time to time although their biomass was small. However, several parts per million of sulfide could have been converted to elemental sulfur by these bacteria.

Returning to the specific question of carbon losses, according to Equation 4, the overall conversion of carbon due to sulfate reduction must have been on the order of 128 mg/l as CO_2 or 35 mg/l as carbon. Overall then, more than one-half of the carbon introduced must have been converted to CO_2.

Another check on carbon transformation is provided by the COD data. According to COD information (see Table 4), the overall reduction in unfiltered COD for the anaerobic pond averaged 1,150 mg/l. Based on the classical oxidation equation:

$$CH_2O + O_2 \longrightarrow CO_2 + H_2O \qquad (6)$$

For which the combining weights are:

$$30 + 32 \longrightarrow 12 + 32 + 18$$

An average carbon release of 460 mg/l in the anaerobic pond would have occurred due to oxidation of 1,150 mg/l of COD. It cannot be decisively stated, however, that the decreases in organic carbon were accompanied by an increase in alkalinity, because the alkalinity was not measured routinely. If an actual loss in carbon occurred, and if nitrogen and phosphate had remained constant while carbon decreased, there would theoretically have been nearly sufficient N and P to satisfy the carbonaceous algae growth potential of liquid entering the algae pond. Even though carbon may have been lost, nitrogen as well as carbon and sulfate was also lost as the carbon was passed through the anaerobic system. The greatest loss occurred in nitrate-nitrogen. Losses in this nitrogen form were as high as 90 percent. Losses in ammonia-nitrogen also amounted to from 20 percent to 90 percent or more of that originally introduced, depending on the time of year. Inasmuch as there was so little nitrogen to begin with, proportional losses in nitrogen kept pace with or exceeded losses in carbon, with the result that a severe shortage of available nitrogen prevailed throughout the series, i.e., in both the anaerobic and the algae pond. Based on the results, the significant conclusion is that it would be difficult to amplify the quantity of nitrogen in the algae portion of the system by adding nitrate or ammonia to the anaerobic pond because they are apparently simply reduced or oxidized and emitted as nitrogen gas or ammonia from the anaerobic pond and thus wasted. With regard to the algae pond, N-fertilization is best accomplished by adding nitrogen to the algae pond directly. The best nitrogen additive to the anaerobic pond probably would be organic N. Organic N addition is potentially provided by settled algae brought in with recirculatant and algae pond effluent.

When the applied BOD to the algae pond is 200 mg/1, 10 to 15 mg/1 of NH_3-N should be adequate to provide for the nitrogen deficiency in the anaerobic pond effluent going to the algae pond. Addition of the nitrogen as anhydrous ammonia probably is to be preferred to adding the nitrogen as nitrate since nitrate would be quickly reduced.

In the past nitrate has been added to sour anaerobic ponds to provide some degree of odor control. However, because of the large amount of nitrate which must be added to provide control (40 percent of the BOD) and its costs, this method of controlling odors would be about 5 times as expensive as would be control with floating surface aerators.

Phosphate added to the anaerobic pond and algae pond evidently was accompanied by its rapid disappearance from the system--probably as a precipitate in the algae pond and possibly by phosphate reduction in the anaerobic pond. According to Waksman and Starkey (10) under anaerobic conditions when organic matter and when phosphates and the necessary bacteria are present, phosphates are reduced to phosphate (H_3PO_3), hypophosphites (H_3PO_2), and phosphine (PH_3) gas with the release of CO_2. Thus, nitrates, sulfates, and phosphates are all potentially reduced in anaerobic ponds.

Although the methodology of nutrient addition was not exhaustively explored in this study, the prior discussion is convincing evidence that the strategy of nutrient addition is at least as important as the nutrient addition itself. On the basis of the limited experience obtained in this study, it is certain that nutrient addition could best be studied in a full-scale system.

The question of why algal or facultative ponds following anaerobic ponds performed poorly in BOD removal is explained on the basis of several facts derived from the study. First of all, because of the efficiency of BOD removal in the anaerobic pond, only a limited amount of BOD remained to be removed in the secondary ponds. Secondly, nitrogen losses in the anaerobic pond limited subsequent algae growth; and finally the presence of large amounts of colloidal suspended solids in the algae and facultative pond effluent imparted to them a BOD of about 100 mg/l even when the loading was very low. Had there been separation of suspended solids from the final effluents, removals would have been greatly improved.

The greatest difficulties in this series of experiments and in the entire study resulted from the fact that the pilot plant was on a shunt from the main factory waste, and consequently was subjected to very frequent failures in the feed system. Inability to control this factor within the budget provided for the study ultimately led to the termination of the studies, and to the conclusion by the authors that any further pilot work with beet sugar wastes should be done with the entire output of a factory rather than with a shunt system.

The fact that nitrogen and perhaps phosphate usually must be added to flume water for aerobic treatment following passage through an anaerobic pond, and the fact that federal and local standards may be established regulating the quantitites of nitrogen and phosphorus which may be discharged into the environment suggests that future studies must involve the control of nutrient additions to give maximum benefit with minimum residual discharge.

Control of effluent BOD as well as effluent nitrogen and phosphorus will almost certainly involve a filtration, coagulation, or separation step to remove suspended solids from final effluents. The development of adequate filtration or harvesting systems is thus an area of significant concern which must be further explored. Effective separation following adequate treatment should permit significant reuse of water for relatively high purposes within a factory.

Predators were extremely difficult to deal with in the algae pond but it is not clear whether the same succession of predators would occur in an algae pond in which there was sufficient nitrogen for algae growth, and hence, in which carbon is limiting. Results obtained in recent studies of domestic sewage systems give some evidence that certain predators such as daphnia cannot withstand the pH changes which occur in carbon-limited algae ponds. Because of their relatively large physical size as compared to algae, predators can be removed from recycled streams by screening. DSM or rotary screens having mesh openings about 200 to 400 microns are effective in predator removal. Both screening and carbon limitation in preference to use of pesticides should be further studied for predator control.

There is no clear explanation for the lack of methane fermentation in the system studied, because as opposed to the findings in this pilot study, methane fermentation is frequently observed in primary beet waste ponds. General observations indicate, however, that the fermentation is most active and visible in those ponds which receive a substantial quantity of mud. Whether this mud traps the gas and, hence causes the release of larger and more spectacular bubbles, or whether it actually acts as an essential substrate surface for methane bacteria is not clear. Because primary sedimentation was used, little mud entered the anaerobic pond of this system. Methane fermentation is always slow to start in new systems. Yet there were periods during earlier runs of this series when the ponds showed some evidence of fermentation more vigorous than that observed during the Fall 1968 campaign. Studies of a pond in which methane fermentation is definitely established and in which the amount of settleable solids introduced can be controlled would be required to explore this phenomenon.

The pertinence of these studies to cold climate installations should be considered. Chemical treatment with lime for pH control and sedimentation with recycling water, and discharge of excess water to an aerated-anaerobic pond is the only alternative thus far explored.(11) This system leads to accumulation of a high carbonaceous load in the recycled water. The maintenance of a high pH causes precipitation and removal of essential nutrients for microbial growth. Thus, decomposition in the anaerobic pond is slow and unbalanced. It is believed that if covered digestion ponds could be developed, it would be preferable to pass wastes through an anaerobic pond prior to chemical treatment. Floating covers for the ponds would preserve factory heat, prevent odors, and permit a high degree of fermentation to occur. Following this fermentation, chemical treatment with supplementary aeration could be applied, and supernatant liquids would be suitable for reuse in the factory or for storage without odor nuisance. Thus, the development of inexpensive pond covers would be a worthwhile study for future investigation.

CONCLUSIONS

Because of the large quantities of mud and extraneous vegetation contained in beet flume water, screening and short-term sedimentation are absolute requirements for pretreatment of beet sugar waste. The degree of sedimentation should be limited in time, however, since carry-over mud seems to have a beneficial effect on fermentation in an anaerobic beet waste pond.

Even after screening and short-term sedimentation, beet sugar waste is so variable in pH, BOD, and composition that short detention period biological processes such as activated sludge, trickling filtration, and highrate ponds cannot be effectively employed as the initial process in a treatment system.

With mechanical surface aeration at 300 lbs of O_2 per day, an anaerobic pond 14 ft deep and one acre in surface area may be loaded at a rate of 1,000 lbs of ultimate BOD or about 700 lbs of five-day BOD/day/acre without giving rise to an excessive odor nuisance.

When factory waste is passed through an anaerobic pond, the discharge has a more uniform pH and a much lower and more uniform BOD than does the original waste. It is thus more subject to effective short detention time secondary biological treatment.

Following passage of waste through an anaerobic pond, the pond effluents are devoid of oxygen, high in a turbidity consisting of microorganism and colloidal-reduced substances such as metal sulfides, high in BOD, and are malodorous. Effluents of this quality must be subjected to aerated treatment before storage, discharge to the environment or reuse.

Aerobic treatment subsequent to adequate anaerobic ponding may involve photosynthetic oxygenation, simple ponding in a facultative pond, or possibly mechanical aeration. The last alternative has not been extensively explored. In the case of photosynthetic oxygenation, loadings of 200 lbs of ultimate BOD/day/acre would be acceptable, whereas in the case of facultative ponds, loadings of 100 lbs of ultimate BOD/day/acre are recommended. In the case of mechanical aeration, it seems likely that to maintain a 4 mg/l DO residual, 1 hp would be required for each 40 lbs of daily ultimate BOD applied to the aeration pond.

Recirculation of secondary pond effluent to the anaerobic pond influent has a beneficial effect upon overall treatment. The effect probably is related to nutrient return and "seeding." A recirculation rate of ½ to 1 Q appears adequate to achieve these benefits.

If recovered waste water from an aeration pond is to be rendered suitable for discharge to the natural environment or for recycle and reuse in the factory, it should be subjected to filtration or separation to remove clay turbidity and bacterial and algae cells. The removal of these substances following anaerobic-aerobic treatment produces a final effluent of fairly high quality having a BOD of less than 20 mg/l.

A minimum of two anaerobic ponds in parallel are recommended to permit cleaning of the ponds and to provide load control. Similarly, parallel aeration or algae ponds are recommended to permit flexibility of operation and maintenance.

Nutrient supplementation with ammonium-nitrogen at 20 mg/l and phosphate at about 10 mg/l is essential for adequate biological aerobic treatment following passage through the anaerobic pond. To avoid losses of nutrients at the anaerobic pond, nutrients should be added following passage of the liquid through the anaerobic pond.

Treatment to remove dissolved nutrients will not be required if nutrient supplementation is carefully controlled. However, to meet the quality standards set up by most of the states, suspended solids will have to be removed from the final effluent by filtration or by some other separation device prior to discharging the effluent into the environment.

The problem of odors in beet waste ponds can only be solved by avoiding overloading of ponds, by providing sufficient treatment area, sufficient aeration and supplementary aeration, and by providing nutrient supplementation. Anaerobic pond loadings should not exceed 1,000 lbs/day/acre, and aeration should be applied at the surface of the anaerobic pond to the extent required to prevent odors. Secondary aerobic ponds should be loaded at not more than 200 lbs/day/acre, and supplementary aeration in the form of flow mixing or possibly surface aerators should be provided. Final effluent must be filtered or otherwise separated to produce a clear supernatant if it is to be suitable to meet most discharge requirements.

REFERENCES

1. Tsugita, R. A., W. J. Oswald, R. C. Cooper, and C. G. Golueke. "Treatment of Sugarbeet Flume Waste Water by Lagooning - A Pilot Study." Journal of the American Society of Sugar Beet Technologists 15:4:282-297 (1969).

2. Beet Sugar Development Foundation. "Facultative and Algal Ponds for Treating Beet Sugar Wastes." Report on WPD 93-01-02 WPD 93-03 partial. Beet Sugar Development Foundation, Fort Collins, Colorado (1967).

3. Oswald, W. J., R. A. Tsugita, C. G. Golueke, and R. C. Cooper. Integrated Designs for Beet Sugar Flume Water Waste Disposal. Presented before the American Society of Beet Sugar Technologists, Phoenix, Arizona, February 1970.

4. Oswald, W. J., R. A. Tsugita, C. G. Golueke, and R. C. Cooper. Anaerobic-Aerobic Ponds for Beet Sugar Waste Treatment. WPD 93-03 (partial), WPD 93-04 (complete). Final report to the Federal Water Quality Administration, Beet Sugar Development Foundation. Fort Collins, Colorado, December 1970.

5. American Public Health Association. Standard Methods for the Examination of Water and Wastewater, 12th edition. New York, 1967.

6. Bronson, J. C., W. J. Oswald, C. G. Golueke, R. C. Cooper, and H. K. Gee. "Water Reclamation, Algal Production, and Methane Fermentation in Ponds." Journal of the International Air and Water Pollution 7:6-7 (1963).

7. Welles Products Corporation, Roscoe, Illinois. Bulletin 49 (1965).

8. Ichikawa, K., C. G. Golueke, and W. J. Oswald. "Biotreatment of Steffen House Waste." Journal of the American Society of Sugar Beet Technologists 15:2:125-150 (1968).

9. Report of the Committee on Water Quality Criteria. Federal Water Pollution Control Administration, U. S. Dept. of the Interior, Washington, D. C. (1968).

10. Waksman, S. A., and R. L. Starkey. The Soil and the Microbe. John Wiley and Sons, Inc., New York (1947).

11. Fischer, J. H., W. Newton II, R. W. Brenton, and S. M. Morrison. Concentration of Sugarbeet Wastes for Economic Treatment with Biological Systems. WPRD 43-01-67, Beet Sugar Development Foundation, Fort Collins, Colorado (1968).

OTHER REFERENCES

1. Walden, C. G. Water Use, Re-Use and Waste Water Disposal Practices in the Beet Sugar Industry of the United States and Canada. British Columbia Research Council, Vancouver 8, B. C. (1965).

STATE-OF-ART SUGARBEET PROCESSING WASTE TREATMENT

by

E. H. Hungerford and James H. Fischer*

INTRODUCTION

A state-of-art study of sugarbeet processing waste treatment practices was conducted by the Beet Sugar Development Foundation with project funds supplied by the Federal Water Pollution Control Administration. The project became effective on April 1, 1969, and was to be completed within an eight month period following that date.

Due to the seasonal nature of sugarbeet processing operations, the waste treatment practices reported were conducted on sugarbeets produced during the 1968 growing period and processed during the 1968-69 processing campaign. A detailed state-of-art document has been prepared and submitted to the Federal Water Pollution Control Administration for future reference purposes.

Sugarbeet and Beet Sugar Production in the U. S.

A brief knowledge of sugarbeet production and the processing of sugar therefrom is essential to an understanding of waste disposal problems. The 12 beet sugar companies contracting for sugarbeets in 1968 processed beets from approximately 1.4 million acres which produced a total of 25 million tons of sugarbeet roots. These sugarbeets were processed in 58 processing plants located in 18 different states producing 3.5 million tons of sugar. These factories are located in significantly different climatic conditions ranging from the hot, arrid conditions of the Imperial Valley of California, to the very cold climate near the north border of North Dakota and from the western edge of California to the state of Maine.

Due to these extreme climatic conditions no one single process is used universally in the physical handling of beets prior to processing nor in the handling of by-products and wastes coming from the purification process. The location of sugar processing plants by states and their rated capacities, actual capacity and projected capacity within a 10 year period of time is shown in Table 1.

---

*Director of Research and Chemical Control (Retired), The Great Western Sugar Company and Manager, Beet Sugar Development Foundation, Respectively, Fort Collins, Colorado.

Table 1. Present and Projected Processing Capacity of Beetsugar Factories by States.

State	Number of Factories	Rated Capacity (1968) Tons beet/day	Actual Capacity (1968) Tons beet/day	Projected Capacity (Within 10 years)
California	10	39,800	37,825	40,000
Colorado	10	25,400	26,500	29,300
Michigan	5	10,900	10,324	11,800
Idaho	4	20,000	20,169	24,950
Minnesota	4	12,800	11,830	14,750
Nebraska	4	9,510	9,974	10,000
Montana	3	8,720	8,450	11,450
Ohio	3	5,000	5,130	5,130
Utah	3	6,350	5,972	6,350
Wyoming	3	7,200	6,817	7,550
Washington	2	10,525	10,250	13,800
Arizona	1	4,200	4,200	4,200
Iowa	1	2,400	1,881	2,400
Kansas	1	3,200	2,605	3,600
Maine	1	4,000	4,000	4,000
North Dakota	1	5,000	3,915	5,000
Oregon	1	6,650	6,600	7,200
Texas	1	6,500	6,500	6,500
Totals	58	188,155	182,942	207,980

Manufacturing Process

The processing capacity (termed slicing capacity) of the 58 factories shown in Table 1 ranges from a low of 1,275 to a high of 7,000 tons per day averaging about 3,250 tons each. Within the factories, basically the same processes are used in all phases of operation. Differences in fresh water use and re-use and in waste loads result from differences in operating practices and, to a minor degree, from differences in equipment. Facilities for handling waste vary markedly from one plant to another. The quantity of fresh water taken into plants in different areas also varies greatly. The total water, including re-used water varies much less. Most of the water used in sugarbeet processing plants is used for condensing vapors from evaporators or pans and for conveying and washing beets. These uses do not require water of high purity, hence considerable recirculation is possible. Differences in fresh water use and recirculation practices affect the quantity and quality of wastes discharged from the plants.

Raw Products Required for Production

The raw materials entering the factories for the beet sugar purification processes are sugarbeets, limestone, small amounts of sulfur, fuel and water. The products are refined sugar, dried beet pulp and molasses (see Table 2).

Table 2. The Average Raw Material Requirements and End Products Produced Per Ton of Clean Beets Processed.

	Per Ton of Beets	
	Tons	Lbs
Limestone	0.04	80
Fuel, coal or gas, BTU	2.5×10^6	
Water, intake, gal.	2200	
Beet pulp, dry	0.05	100
Sugar produced	0.13	260
Molasses	0.05	100
Waste water, gal.	2100	
	At Steffen Factories	
Molasses worked	0.05	
Additional limestone	0.02	
Additional sugar produced	0.015	
Steffen filtrate, gal.	90	

Wide differences in these quantities are experienced at individual factories, particularly with regard to fresh water intake. Eight of the factories surveyed indicate that less than 900 gallons of water were required per ton of beets sliced (1 only 215) while 8 of the factories reported requirements of 4,000 gallons or more. The average as noted is 2,200 or approximately 1 gallon per pound of sugarbeets processed.

Within the last 2 decades two important equipment changes have been made in the U. S. beet sugar factories which have reduced water usage and resulting quantities of wastes. These are the installations of (A) continuous diffusers and (B) pulp driers. The continuous diffuser permits factories to operate with lower quantities of diffuser supply water.

Prior to the installation of pulp driers in beet factories, the pulp was conveyed to pits, the drainage from which became a high BOD waste. With the installation of pulp driers, improved pulp presses were installed to more efficiently dewater the pulp prior to dehydration. In nearly all of these installations, the pulp press water is returned back to the diffuser, reducing the diffuser supply water requirements, in addition to reducing the discard waste load.

The end product molasses is utilized for several different purposes, most of it being used as an additive to the dried pulp, improving its nutrient value. In 21 beet sugar factories the Steffen process is used, which extracts additional sucrose from the molasses prior to its use as an additive to dehydrated sugarbeet pulp.

WASTE PRODUCTS OF A MODERN BEET SUGAR FACTORY

The principle wastes from the beet sugar purification processes are: flume and washing water; barometric condenser water; lime mud (carbonate cake); general wastes (floor washes, equipment washes, etc.); and Steffen waste at those factories using the Steffen process.

Flume or Transport Water

Sugarbeets are transported directly from rail cars, trucks or moved from storage piles adjacent to the factory by water flowing in a narrow channel (flume) which provides gentle handling of the fragile beets and removes most of the adherring soil. Beets are lifted from the flume to a washer and subjected to final washing before entering the factory where they are sliced into thin narrow strips called cosettes before entering the diffuser. The combined flume and washer water constitutes the largest single usage of water ranging from 1,200 to 4,000 gallons per ton of beets, averaging about 2,340. This is not necessarily all new water.

In most factories flume water is recycled in varying degrees after separation of much of the suspended solids. The flume water carries in addition to suspended matter, dissolved solids which have diffused from the beets. In many factories water for fluming is drawn from the barometric condenser seal tanks; in others, fresh water is used either alone or as a supplement to condenser water. The use of warm condenser seal tank water for fluming is necessary in cold climates to thaw frozen beets.

The physical removal of suspended solids from flume water is the first treatment step. In all but 8 of the 58 factories flume water is screened to remove root fragments, leaves and weeds. The screenings are either removed by a local farmer and used as a livestock feed or are cycled through a hammer mill and then dried on beet pulp.

The amount of soil (dirt tare) varies greatly from one beet area to another and from season to season. Under wet harvesting conditions the soil adherring to beets to be processed may exceed 10 percent of the weight of beets and as little as 3 or 4 percent on beets delivered from light sandy soil. In any case, suspended solids are removed in part from flume water in settling ponds or by clarifers. Under normal conditions, the average dirt tare at an average factory in the United States amounts to between 5 and 6 percent of the beet weight. A factory slicing 4,000 tons of beets during a campaign will accumulate between 20 to 24 thousand cubic yards of dirt in its settling ponds. At Nyssa, Oregon for instance, 53,000 cubic yards of dirt were removed from lagoons in 1968 after processing 995,000 tons of beets.

Grit separators are used by 5 factories to remove coarser material from recirculated flume water and 10 factories used conventional clarifers to effect more complete separation of suspended solids before recirculation or discharge to ponds. The clarifer underflow is pumped to mud ponds. At 12 factories milk-of-lime is added to the flume water as it leaves the screens or enters the ponds. This serves to keep the pH at a level which impedes bacterial action, serves as a flocculating agent and reduces odors. Where flume water is recycled back to the flumes the addition of lime permits the use of smaller settling lagoons in the system.

Barometric Condenser Water

Cold water in large quantities is required in the barometric condensers of the evaporators and pans. The quality of this water is not necessarily important, however, it is usually relatively pure due to its source. The amount of condenser water used varies from 1,300 to 4,500 gallons per ton of beets, averaging approximately 2,210. In 20 of the factories condenser water is cooled by cooling towers or spray ponds and recycled to the condensers. In 38 of the factories, spent condenser water is frequently re-used principally for fluming beets. In many of these cases, condenser water is the only source of flume water.

In factories where recycling of flume water is practiced, it is often advantageous to discharge the condenser water directly to streams. By using this flow pattern a large volume of effluent containing relatively little BOD bypasses the waste ponds. The BOD in spent condenser water, however, is not negligible, often amounting to 0.5 pounds per ton of beets. Unless cooled, the temperature is about 50°C and the dissolved oxygen content near zero. The sugar lost by entrainment in condenser water amounts to approximately 1,800 pounds per day in a plant of 2,500 to 3,000 tons capacity.

Condenser water picks up ammonia from the evaporating juices, hence is always alkaline ranging from 8 to 10 pH, but usually less than 9. The discharge of this slightly alkaline water to streams has to this date rarely met serious objection from pollution control authorities. The more serious objection comes from the high temperature, particularly where discharge is to streams which are small and sluggish. This localized temperature increase in the stream sometimes causes a change in aquatic life. This has not been a problem with agricultural-industrial classified water.

Lime Mud (Precipitated Calcium Carbonate)

The high lime requirements for juice purification in the beet sugar process has resulted in the industry as a whole becoming one of the largest producers of lime in the country. The precipitate of calcium carbonate (lime cake or mud) containing raw juice impurities is removed from the juice by the rotary vacuum filter process which discharges a cake containing about 50 percent water. The cake is slurried with water and pumped to a lime pond. Water used for this purpose may be either fresh water, condenser water or other in-house hot water. The quantities actually used vary from less than 10 gallons per ton of beets to more than 100, the average being approximately 50 gallons per ton of beets. The dry solids in the lime mud discharge by the factory ranges from about 4 to little more than 6 percent of the weight of beets. The lime cake from the rotary filters is slurried with water to obtain a pumpable mixture of about 25 percent solids.

Of the 58 factories, 53 discharge lime cake to separate lime ponds, 5 discharge it to the flume or general ponds. At 27 of the factories no overflow from these ponds has been reported. The lime mud transport water at these factories is usually lost by seepage or evaporation.

At 22 of the plants, however, the pond overflow runs into the flume or general ponds, whereupon the lime pond effluent is subjected to the same treatment as the flume and general wastes. The average accumulation of lime cake is approximately the same by weight as that of flume sediments, namely 20 to 30 thousand tons per year per factory. Only 2 factories now reburn lime cake for the production of lime. One uses a horizontal rotary kiln, the other a multiple hearth-type kiln.

In some instances lime cake is used for agricultural purposes. The rather large reserve of lime cake at one factory is used by farmers on peat soil at a rate somewhat faster than it is being produced. As a general practice, two or more lime ponds are available at a factory enabling the operators to leave one out of service each year, so it can be dried and dug out.

Steffen Dilution Water

At the 21 beet sugar factories employing this Steffen's process, molasses containing about 50 percent sucrose is diluted with cold fresh water producing a solution containing from 5 to 6 percent sucrose. This process produces a precipitate and a filtrate, the filtrate becoming a waste. At 14 factories this filtrate is concentrated (called concentrated Steffen filtrate), is mixed with pressed beet pulp and dried. At the other 7 Steffen factories the waste is discharged to shallow ponds where it dries or is lost by seepage.

The disposal of Steffen waste has been one of the most perplexing problems, the solids in the wastes consisting principally of sodium and potassium salts and nitrogen compounds.

General Wastes

Heating and evaporation of juices by steam or vapors result in the production of quantities of condensed waters ranging from 150 to 200 percent of the weight of beets sliced. The purest of these condensates are collected and used as boiler feed. Normally no other water is used for this purpose. Condensed waters are also used in part for diffuser supply for filter press wash, (washing of lime cake precipitate), centrifugal wash and house hot water for cleaning evaporators, floors, etc. Some of the cleaning operations require the use of acids or caustic soda. These wastes are sent to what is called the main sewer and to the general ponds where in many instances the flume water, lime pond overflow are ponded and treated. The miscellaneous or general wastes are intermittent and often cause sudden changes in the pH of the effluent to the ponds. This accounts in part for the erratic behavior of organisms customarily associated with typical waste treatment practices.

CONCLUSIONS

The high volume of water used in the art of refining sugar from sugarbeets, the relative dilute nature of the solids and the variable pH create unique conditions for direct application of typical treatment systems. This study has shown that the beet sugar industry has significantly reduced its discharge of BOD-demanding wastes through application of a wide variety of recycle and conservation practices. Waste discharge has been reduced from a level of 30-40 pounds, per ton of beets in less than two decades to a 1968 average of 3.15 pounds per ton of beets. Complete retention of all discharge on the factory premises is practiced at a few locations. Release of water to match receiving water quality standards is possible provided time and economics permit. Additional technical developments will be required to solve "spin-off" problems associated with principal treatment operations.

PRINCIPLES OF NUTRIENT CONTROL FOR AGRICULTURAL WASTEWATERS

by

Dr. Raymond C. Loehr*

INTRODUCTION

Agricultural production has become more concentrated and efficient in response to our need for food. Farm size and productivity per farm worker have increased. The effect of this productivity can be observed by noting that in 1940 a farm worker produced enough farm products for nearly 11 persons while in 1969, a farm worker produced enough for 45 people, over a 300 percent increase. In 1969, about 3 million farms, half the number 30 years ago, were supplying the nations needs. The remaining farm and animal production operations have greatly increased in size and number of animals per operation. Scarcity of labor and desire to replace manual with mechanical labor has led to technical advances in crop production and harvesting, animal housing and feeding, food processing, and waste management. There has been a constant consolidation of smaller operations into larger ones with a resultant increase in more and larger point sources of pollution with greater needs for control. The changes in the food processing industry have paralleled similar changes in the grain production and animal production sectors of agri-business.

Population growth and consumer desire are important factors in determining future agricultural changes. Per capita consumption of meats, poultry, and processed fruits and vegetables is increasing while that of many dairy products, eggs, fresh fruits and vegetables, and cereal products have decreased. If these rates continue, significant increase in cattle and broiler production, and in food processing operations will occur to meet both the population growth and increased per capita consumption. Agricultural waste management problems in these industries will increase accordingly. The production of other food products will increase at a rate close to or slightly less than that of the population growth.

Had agricultural production practices remained static, environmental problems caused by agriculture may have remained minimal. However, real and potential environmental quality problems have accompanied the changes in agricultural productivity in recent decades.

As yet we are unsure of the specific role of agriculture in the overall environmental quality picture. Definitive information on the contribution of agriculture to general as well as to specific water, air, and

---

*Professor of Civil and Agricultural Engineering, Cornell University, Ithaca, New York.

Preceding page blank

nuisance problems is relatively unknown in comparison to contributions from domestic and industrial sources. The available information suggests that agriculturally caused pollution problems can be significant especially at the regional and local level. Data on fish kills from feedlot runoff, nutrients in the runoff from cultivated lands and those used for disposal, the quantities and pollutional strength of animal and food processing wastes produced nationally, nuisances due to odors and dusts, and the increasing size of agricultural production operations indicates that considerable attention must be given to the development of proper methods to handle, treat, and dispose of agricultural wastes with minimum contamination of the environment. Common sense approaches to waste management can reduce many of the gross pollution problems associated with animal production.

Information on the interrelationships of agricultural production and waste management and on the ultimate costs of feasible solutions remain scarce. It is obvious that compromises are necessary between agricultural production and environmental quality control to assure adequate food for the nation, adequate profit for the producer, and an acceptable environment for the public.

Data presented at this Symposium by Rose et al(1), and Hudson(2) on the overall magnitude of the food processing waste problem and by others on specific industries and on the costs of possible solutions to these problems, materially has assisted in placing the problems and potential solutions in proper perspective. Additional information of this nature will help channel the necessary developmental and demonstration funds in the proper direction and will help the better pollution control approaches to be utilized.

Many of the research, large scale, and field studies being conducted to determine feasible waste management systems emphasize the removal of oxygen demanding material such as solids and BOD. This approach is very appropriate and should be continued. However, an equal emphasis should be given to the control of nutrients in agricultural wastewaters. Many of the Symposia speakers referred to possible problems from excess nutrients but only in an oblique manner.

The current emphasis on conventional oxygen demanding materials and solids reflects the problems of perfecting the technology necessary to remove these materials. The better approaches for such technology are becoming clearer. At the present time, adequate waste treatment technology does not exist to control or remove nutrients from agricultural wastewaters.

With the national emphasis on control of nutrients from domestic and industrial sources, it is unlikely that agricultural wastes can escape the same scrutiny for very long. The purpose of this paper is to discuss the principles of nutrient control that can be applied to agricultural wastewaters and to illustrate the application of these principles to specific agricultural wastes.

NUTRIENT CONTROL

General: The quality and characteristics of agricultural wastes are diverse requiring that the nutrient control measures be applied in different ways to each situation. The principles of such control permit decisions as to which control measure will be most effective.

Agricultural wastes vary from liquid wastes to liquid slurries, from continuous to variable flows and concentrations, from nutrient deficient to nutrient excess wastes, and from seasonal to year-round waste loads. No single treatment system or approach is likely to be adequate for waste management at all agricultural operations. Geographic location, availability of land, and proximity to ground and surface waters will place restrictions on feasible nutrient control systems.

Environmental Quality Problems: Excess nutrients released to the environment can cause a number of environmental problems such as an additional oxygen demand caused by reduced nitrogen compounds, stimulation of aquatic plant growth by nitrogen, phosphorus, and other nutrients in wastewaters, and excess nitrates in groundwater as a result of wastes discharged on the land. The nitrogenous oxygen demand (NOD) in surface waters is the result of the oxidation of unoxidized nitrogen compounds. Ammonia is the form of nitrogen in the effluents of many treatment processes. The ammonia is oxidized microbially to obtain energy for cell synthesis. If all of the ammonium ions were oxidized, 4.57 pounds of oxygen would be required per pound of nitrogen oxidized to nitrate. About 0.8 percent of the nitrogen converted into cell material is fixed by the bacteria. Measurements of oxygen utilization indicate the following oxygen requirements: 3.22 mg/l O_2/mg/l NH_4-N oxidized to NO_3-N and 1.11 mg/l O_2/mg/l NO_2-N oxidized to NO_3-N (3). Some streams that receive treated wastewaters have the nitrogenous oxygen demand as a major demand on their oxygen resources. The NOD in surface waters can be controlled by oxidizing the nitrogenous compounds in a treatment facility rather than in the streams. This method of control will require additional aeration capacity and increased solids and liquid detention time in the treatment plant.

The growth of unwanted aquatic plants, such as excessive algae, rooted plants, or water hyacinths, can be stimulated by the reduced and the oxidized forms of nitrogen, by phosphorus, and by the addition of other nutrients that may be limiting in the surface waters. These nutrients can be added either from direct discharge of treated or untreated wastes or by land runoff. The control of the unwanted aquatic matter can be accomplished by reducing the concentration of a critical nutrient to below the limit necessary for aquatic plant growth. No one nutrient is critical in all waters and control procedures will vary for different water basins. Control of nutrients in land runoff is more difficult to achieve.

High nitrates in ground waters can be a cause for rejection of these waters for potable use. Wastes discharged to the land, such as septic tank effluents, animal wastes, and sewage sludges can contribute to this problem. Actual cases attributable to agricultural wastes are rare but caution is advised when planning disposal of wastes on land since once the ground waters contain excess nitrates, removal of the nitrates is both difficult and costly. Control of this problem is to avoid the application of excess nitrogen compounds to the land, and to incorporate the wastes with good land and crop mangement practices. Control is a question of how to manage the land disposal process without causing secondary problems such as land runoff and ground water problems.

A somewhat peripheral problem assoicated with agricultural wastes is the release of nitrogen oxides to the atmosphere. These releases would occur from denitrification on the land and in waste storage units. Animal confinement facilities are a more likely source of these emissions than are food processing operations. National ambient air quality standards of 100 mg/m^3 have been proposed(4) for nitrogen dioxide. Releases of nitrogen oxides from agricultural operations are uncontrollable, should be considered as part of the natural background levels that exist in the environment, and should not be subject to air quality controls.

Control Measures: The control of excess nutrients released to the environment is of greater importance than removal of the excess nutrients. Many approaches can be used in agricultural operations for such control. These include separation at the source and recycle through the food chain in some manner, incorporation of nutrients into microbial cell mass and separation of the cells from the liquid streams followed by recycle or disposal of the cells, and land disposal. Waste treatment processes can provide for both removal or control.

The type of control to be practiced will depend upon the type of nutrient problem. Nitrogenous oxygen demand can be controlled by sufficient oxidation before discharge, eutrophication by minimizing the release of nutrients, and ground water quality by managing land disposal practices. A factor having a significant effect on applicable control measures will be the variation in waste flows and characteristics. As noted by many at the Symposium, waste flows and loadings from food processing operations can be extremely variable with large variations occurring throughout the working day and the processing season. In addition many of these processing operations are seasonal functioning over only a few months of the year. Lesser variations are to be expected at confined animal production operations since a more consistent operation is practiced. Meat-packing facilities are not seasonal but are subject to a wide variation of flows and loads during the working day.

Feasible control measures will differ depending upon whether the wastes are discharged to an aquatic environment or to the land. Phosphorus can be a more critical nutrient when wastes are discharged to surface waters while nitrogen is more critical when land disposal is practiced. Due to the varying sources of nitrogen in the environment, phosphorus control is more feasible for wastes discharged to streams. When wastes are discharged to the land, the phosphorus adsorbs on to clay particles and will move only slightly from the point of disposal. Control of phosphorus on the land is one of erosion control since if the soil loss can be minimized, phosphorus loss to the surface waters can be minimized.

Nitrogen compounds will be oxidized to the soluble nitrate form in the soil which can move with the land runoff and ground water percolate. In most soils, a portion of these nitrates will denitrify and be released to the atmosphere and a portion will be utilized in crop growth. The quantity removed from the soil in this manner will depend on how the land and crops are managed. To minimize nutrient loss in surface runoff, wastes should be incorporated into the soil as soon as possible after disposal. The quantity of excess nitrates that reach the ground water will be a function of the water movement through the soil and is related to the type of soil, the organic matter in the soil, and the precipitation rates.

Control Methods: The best way to control the effect of any waste on the environment is not to permit excess quantities to be discharged. Source control, by-product recovery, and process modification are key components to this control method. This approach has been exemplified by the national use of water quality criteria in which the goal is to see how much wastes we can keep out of waters rather than to see how much can be discharged without adverse effect.

Many projects at the Symposium emphasized efforts to accomplish this goal. While the general aim of the projects may have been to recover a useful by-product, such as a protein, the effort represents a valuable nutrient control measure. Examples that were presented include protein and by-product recovery from shellfish, dry caustic peeling of vegetables and fruits, potato starch separation and evaporation recovery of protein containing wastes, fungi and microbial solids production in biological waste treatment, and whey protein separation. In-plant change for blood capture was among the nutrient control measures discussed for meat processing operations.

The key to a recovery and recycle process remains the sale or use of the reclaimed or separated material. The hope expressed by many at the Symposium was that much of this material would be used as animal feed. To be competitive as animal feed, handling and transportation costs cannot be excessive. The source of the by-products should be close to animal feeding operations. Not all food processing operations are within economical transportation distance of feeding operations.

Recovery and recycle does not erase the solids or nutrient problem although it may transpose it in place and form. In the above cases the reclaimed wastes from food processing operations will contribute to an animal waste problem. As long as the new place or form is less objectionable, less pollutional, or meets another need of man such as food production, recycle will be successful. One of the greatest hopes for the future for control of industrial pollution, including nutrient control, lies in separation of wastes at the source, process modification, solids and nutrient recovery, and recycle.

The incorporation of nutrients into microbial solids offers another method of nutrient control especially for vegetable and fruit processing wastes which are highly carbonaceous and which require nutrient addition. Joint treatment of these wastes with wastes containing excess nutrients, such as domestic, industrial, or other agricultural wastewater, can be of mutual benefit. Four papers provided interesting information on the balance of nutrients needed for microbial growth and pointed out the problem of carefully controlling the addition of nutrients to nutrient deficient wastes. An excess of nutrients added to deficient wastes can be the cause of excess nutrients in the resultant effluent.

The common approach of adding nitrogen and phosphorus to nutrient deficient wastes to assure adequate nutrients is to attempt a BOD:N:P ratio of 100:5:1. This ratio is satisfactory if one wishes to assure no nutrient deficiency, but is of little use if the purpose is to have the nitrogen and phosphorus levels be low in the effluent. The above ratio was designed to assure adequate nutrients in high rate biological treatment. However, for a stationary or declining growth biological treatment system, such as are most treatment systems, the above ratio will result in excess nutrients in the effluent. With the long solids retention time, a matter of days, in the common treatment systems, endogenous respiration of the microbial cells will release nutrients to the system. These nutrients will be used in the synthesis of new microbial cells. Approximately 0.11 lbs of nitrogen will be released from the oxidation of 1 lb of microbial cells.

The addition of nutrients should be added in relation to the rate of cell synthesis. This rate is low in biological systems with long solids retention times. To avoid an excess of nutrients in the effluent, nutrients should be added to the system in proportion to the nutrients lost in the microbial solids wasted or lost from the system. The quantity of nutrients to be added would be the difference in the amount of nutrients lost in the microbial solids leaving the system and in the nutrients entering the system. Burm(5) added nutrients at the 100:5:1 ratio and with a solids retention time of about 200 days felt that nitrification was occurring, indicating that there was an excess quantity of nitrogen in the system.

Church(6) obtained a high mycelium growth of 50 percent of the BOD in the influent and attempted to keep the cells in a growth stage. By doing so the added nutrients were kept in the fungal solids since the clarified effluent had an ammonia nitrogen concentration of 0.2 mg/l and a soluble phosphorus concentration of 0.01 mg/l. The data emphasize another point. Even if nutrients are tied up in microbial cells, the cells must be removed from the effluent to achieve positive nutrient control. Degradation of these solids in the receiving stream will release a portion of the nutrients. The need for solids separation for nutrient control is apparent if an oxidation pond is used. These ponds are organic matter generators and high removals of BOD, solids, and nutrients will not be achieved unless the solids in the effluent are removed. Harvesting aquatic and algal solids for animal feed offers one possibility for nutrient control(7).

Parker and Skerry(8) provided information on an applicable BOD to nitrogen ratio when he noted that a ratio of 100 :2 or 100:1.5 was satisfactory in treating cannery wastes before performance decreased. Eidsness(9) collected field data on the treatment of citrus wastes that indicated that a BOD:N ratio of about 100:3 and a BOD:P ratio of about 100:2 was satisfactory. Therefore, if one wants to control nutrients in a nutrient deficient waste, the nutrients should be added in relation to the cell sythesis rate. In controlling nutrients, one should be careful to avoid nutrient limiting conditions since poor growth microbial characteristics and poor microbial solids settling can occur under these conditions.

The use of microbial synthesis for nutrient control will not be effective with animal wastes or meat and poultry processing wastes since nutrients are in excess of the amounts required for synthesis. Paulson(10) and Baker(11) provided data to illustrate this point. Addition of a carbonaceous waste or chemical to such wastes to increase microbial growth and nutrient control rarely is feasible due to the cost of treating the added organic matter.

The treatment processes that can be used with agricultural wastes, in addition to algal and microbial synthesis are phosphorus precipitation, ammonia stripping, and nitrification-denitrification. In addition, land disposal or management can be used. Phosphorus precipitation will require chemical addition, solids separation, and solids disposal. This will be needed only where disposal to surface waters is practiced. According to Rose(1), about 55 percent of the canning and freezing liquid wastes are disposed by spray irrigation. With animal wastes, over 90 percent are disposed of on the land. Under these conditions, phosphorus removal prior to disposal will not be needed since the phosphorus will be removed from the liquid or slurry by a combination of crop and grass growth and by adsorption on to soil particles.

Ammonia stripping is a possibility since the form of nitrogen is either ammonia or organic nitrogen which will be microbially converted to ammonia. The pH of the wastewaters must be controlled to above 9.5 for feasible removal and above 10 for rapid removal. The process is adversely affected by low temperatures and high viscosities. While stripping towers have been successful with municipal wastewaters, they will not be effective with agricultural wastes due to their high solids and organic content. Possibilities of diffused or rotor aeration exist for ammonia stripping with high strength wastes. A secondary concern is the fate of the ammonia released to the atmosphere since it is not lost to the environment, only more broadly distributed. Ammonia stripping is not likely to have a large impact or be a highly feasible nitrogen control process for agricultural wastewaters.

The combination of controlled nitrification followed by denitrification offers an opportunity for nitrogen control. The solids retention time of the biological system must be maintained greater than the growth rate of the nitrifying bacteria to achieve consistent nitrification. A minimum solids retention time of 3-4 days at 20°C and about 5-6 days at 15°C is required in operating systems. A critical dissolved oxygen concentration has not been definitely determined but it appears to be about 0.5 mg/l. To assure that dissolved oxygen levels in the biological unit do not inhibit nitrification, it is desirable to keep the dissolved oxygen in the unit above 1.0 mg/l. Because the oxygen transfer rate is a function of the dissolved oxygen deficit, there is little advantage in maintaining a dissolved oxygen concentration greater than 2.0 mg/l. A loading factor of 0.3-0.4 lb BOD/day/lb MLSS in an aeration tank has been suggested as an upper limit to achieve good nitrification in aerobic biological units.

Vegetable, fruit, and meat processing wastes exhibit variable flow and load characteristics. These variations can provide difficulties in consistently obtaining nitrification with such wastes. Problems include maintenance of an adequate solids retention time and dissolved oxygen levels. Nitrification can occur but since control is difficult and since nitrification must precede denitrification, the practical use of this approach with food processing wastes remains doubtful.

Two areas where the process may be feasible are in the denitrification of irrigation return waters and in aerobic systems in confined in-house animal production operations. Nitrogen removal from irrigation return waters has been extensively evaluated(12, 13) and requires the addition of a source of carbonaceous material. Cyclic nitrification has been observed in oxidation ditches treating animal wastes. Long detention times in these systems are common as are low loadings. The development of controlled systems for these wastes will extend the knowledge of sanitary engineers since to date such methods have been applied primarily to low strength wastes such as municipal wastewaters.

Probably the most feasible and natural nutrient control method is to use the land as a waste disposal media. The challenge is to discharge the wastes to the land with proper managment to enhance the productivity of the land yet obtain no adverse environmental effects. Possible adverse effects include inhibition of a crop, ground water pollution, and excessive runoff. The amount of wastes that can be disposed of on a given acreage of land will depend upon the type and location of the soil, the crops to be grown, the characteristics of the wastes, and environmental conditions such as temperature, nearness to surface waters, and rainfall patterns. Information of this type is only beginning to become available. More data is needed to answer questions such as how much, when, where, and how to integrate land disposal of wastes with land and crop management.

Nitrogen removal is the primary nutrient concern with waste disposal on the land. With nitrogen deficient wastes such as fruit and vegetable wastes, this may not be a problem. However, for wastes such as animal wastes and meat processing wastes which contain excess nutrients, greater caution is warranted. Two nutrient control processes that can be controlled through judicious timing and rates of application of disposal on the land are incorporation into crop growth and denitrification in the soil. These methods are not ones in which sanitary or agricultural engineers are very knowledgeable. Both professions must rely on the advice of agronomists and soil scientists.

SUMMARY

The items that have been emphasized can be summarized as follows:

a) Control of nutrients in agricultural discharges will become more important in the near future as the water resource policies of the nation receive greater scrutiny.

b) Considerably better data on the nutrient concentrations currently discharged and on the processes that can be utilized for control is needed. Suitable technology for such control is lacking and national efforts on nutrient control of agricultural wastes are minor.

c) This information is needed not only to arrive at technical decisions for proper control but also to obtain estimates of the cost involved.

d) Fruit and vegetable processing wastes represent fewer nutrient control problems since many of these wastes are nutrient deficient. Care should be taken in adding nutrients to biological treatment systems to avoid causing nutrient control problems by over-dosing. The added nutrients should be related to the synthesis rate of the microbial solids and the difference in the nutrients lost from the system in wasted microbial solids and those entering the system.

e) A greater concern for nutrient control will exist with meat, poultry, and fish processing wastes and with animal manures. Such control represents a challenge to those interested in waste management due to the nature and concentration of these wastes.

f) The two most feasible approaches for nutrient control are separation at the source, recovery, and recycle and land disposal. The success of recovery and recycle depends upon the use of the product and the success of land disposal depends upon a much better knowledge of the land as a disposal media. The fundamentals of the processes remain the key. Black box research will not be satisfactory.

REFERENCES

1. Rose, W.W., Mercer, W.A., Katsuyama, A., Olson, N., Sternberg, R.W., Brauner, G.V., and Weckel, K.G. "Production and Disposal Practices for Liquid Wastes from Canning and Freezing Fruits and Vegetables," Presented at the Second Nat. Sympos. on Food Proc. Wastes, Denver, 1971.

2. Hudson, H. "Solid Waste Production in the Food Processing Industry," Presented at the Second Nat. Sympos. on Food Proc. Wastes, Denver, 1971.

3. Werzernak, C.T. and Gannon, J.J. "Evaluation of Nitrification in Streams," JSED-ASCE 94 SA 5 883-895, 1968.

4. Shearer, S.D. "The Clean Air Amendment of 1970 and Air Pollution Aspects of the Food and Agricultural Processing Industry," Presented at the Second Nat. Sympos. on Food Proc. Wastes, Denver, 1971.

5. Burm, R.J. Cochrane, M.W., Dostal, K.A. "Cannery Waste Treatment with RBC & Extended Aeration Pilot Plants," Presented at Second Nat. Sympos. on Food Proc. Wastes, Denver, 1971.

6. Church, B.D., Nash, H.A., Erickson, E.E. and Brosz, W. "Continuous Treatment of Corn and Pea Processing Waste Water with Fungi Imperfecti," Presented at the Second Nat. Sympos. on Food Proc. Wastes, Denver, 1971.

7. Oswald, W.J. "Fundamental Factors in Stabilization Pond Design," Advances in Biological Treatment, Eckenfelder, W.W. and McCabe, J. editors, MacMillan Co., 1963.

8. Parker, C.D. and Skerry, G.P. "Cannery Waste Treatment in Lagoons and Oxidation Ditch at Shepparton, Victoria, Australia," Presented at the Second Nat. Sympos. on Food Proc. Wastes, Denver, 1971.

9. Eidsness, F.A., Goodson, J.B., and Smith, J.J. "Biological Treatment of Citrus Processing Wastewaters," Presented at the Second Nat. Sympos. on Food Proc. Wastes, Denver, 1971.

10. Paulson, Wayne L., Kueck, Darwin R., & Kramlich, W.E., "Oxidation Ditch Treatment of Meat Packing Wastes," Presented at Second Nat. Sympos. on Food Proc. Wastes, Denver, 1971.

11. Baker, D.A., White, J., and Wymore, A. "Treatment of Meat Packing Waste Using PVC Trickling Filters," Presented at the Second Nat. Sympos. on Food Proc. Wastes, Denver, 1971.

12. McCarty, P.L., Beck, L., and St. Amant, P. "Biological Denitrification of Wastewaters by Addition of Organic Materials," Proc. 24th Annual Purdue Indust. Waste Conf. 1969.

13. Tamblyn, T.A. and Sword, B.R. "The Anaerobic Filter for the Denitrification of Agricultural Sub-surface Drainage," Proc. 24th Annual Purdue Indust. Waste Conf. 1969.

OXIDATION DITCH TREATMENT OF MEAT PACKING WASTES

by

Dr. W. L. Paulson, D. R. Kueck & W. E. Kramlich*

INTRODUCTION

The purpose of this paper is to present a progress report on a demonstration grant (12060 EUB) from the Environmental Protection Agency-Water Quality Office to study oxidation ditch treatment of meat packing wastes at the John Morrell & Co. plant in Ottumwa, Iowa. The demonstration grant includes design, construction and post-construction studies.

BACKGROUND

John Morrell-Ottumwa, Iowa

Morrell & Co. located meat packing operations in Ottumwa in 1877. The plant was nearly destroyed by fire in 1893. In the early 1900's, the facilities were rebuilt and expanded. Several of the buildings currently in use date back to this period.

The plant currently employes approximately 2600 people. The average daily live weight processed is 2.2 million pounds. An average of 5000 hogs and 800-1000 beef are processed in a one-shift operation, normally 5 days per week.

The plant is located near the Des Moines River. This river basin drains central Iowa. A flood control reservoir, upstream from Ottumwa, completed in 1969 currently provides a minimum stream flow of 300 c.f.s. River surveys were conducted by the State, Morrell personnel and consultants in the 1940's. As a result of these findings, several in-plant control measures were begun to improve the quality of waste discharge. These measures and others were instituted during the 50's and early 60's. Daily losses of biochemical oxygen demand, protein and grease in pounds per 1000 pounds live weight were reduced from 35 to 15, 18 to 8 and 20 to 6, respectively. Some of the measures utilized are dry rendering, dry removal of beef paunch, installation of catch basins and various separation and housekeeping techniques.

In 1966, the State of Iowa conducted a study of conditions in the Des Moines River and waste contributions from the Ottumwa area. Based on the established Iowa water quality criteria for the Des Moines River downstream from Ottumwa, the State set an allowable biochemical oxygen demand (BOD) discharge for meat packing wastewater from Morrell & Co. of 2200

---

*Associate Professor, Civil Engineering, University of Iowa, Iowa City; Group Supervisor, Research & Development, John Morrell & Co., Ottumwa, Iowa; Vice President & Director, Research & Development, John Morrell & Co., Chicago, Illinois.

lbs/day.

At this time, the City of Ottumwa's (33,000) wastewater treatment plant was a primary treatment plant. Recently (1970-71), the City has approved plans and received federal support to expand their plant to include trickling filter secondary treatment.

During 1966-67, extensive in-plant waste surveys were conducted at Morrell to determine the wastewater quantities and characteristics for treatment plant design. It was decided that from 3.25 to 3.50 million gallons of watewater per day would require treatment. The daily (5 day week) BOD loading was predicted to be 38,000 pounds.(1)

Design Approach

Dr. H. O. Halvorson, consultant to Morrell and the Morrell engineering and research staff investigated several meat packing waste treatment methods that might be applied at Ottumwa. Dr. Halvorson recommended that the oxidation ditch activated sludge process be investigated for the Morrell plant. This process (known also as the Pasveer process) has been utilized extensively in western Europe in the 1950's and '60's. More than one hundred such plants have been installed in the U.S. and Canada.

Dr. Halvorson had observed the oxidation ditch process in Europe and had worked on similar plants in the United States. He also cited a study by F. Guillaume(2) of the Ontario Water Resources Commission reported in 1964. Guillaume had concluded that "on the basis of the acquired information, that the oxidation ditch treatment system is rather inexpensive to construct and simple to operate, and that it produces an acceptable effluent consistently." This conclusion was made with small municipalities in mind as he further stated that an upper limit for design population for which the oxidation ditch would still be preferable was not indicated.

Municipal oxidation ditch plant performance at Glenwood, Minnesota and pilot plant studies on meat packing wastes at Arkansas City, Kansas(3) were used to provide design information. Overall BOD reductions from 61 to 92 percent were obtained at Arkansas City with detention times from 8 to 48 hours and BOD loadings from 8 to 65 cu. ft. of ditch/lb of BOD. Dr. Halvorson recommended a minimum detention time of 24 hours with a maximum BOD loading of 1 pound of BOD per 30 cu. ft. of channel. Additional design criteria were proposed based in part on the above plants. A federal research and demonstration grant was then obtained to partially support the project.

The final plant design was developed by Mr. George E. Ahrens, Engineer and Project Director for Morrell & Co. at Ottumwa, with the assistance and approval of Morrell & Co. engineering staff and Water Quality Office of Environmental Prot. Agency project officers. Plant features and details will be presented in a subsequent section.

Bids were received in September 1968. The total plant cost estimate was $780,000. Wastewater flow was first accepted in November 1969. Major mechanical and other plant start up difficulties developed and continued until fall 1970. Some of the problems continue but it has been possible to begin to determine the potential of the process and areas of plant design modification or change to meet the process goals.

Post Construction studies--statement of project objectives

The primary objective of this demonstration project is to determine the effectiveness of the channel extended aeration activated sludge process in achieving organic removal from packinghouse wastewater. The performance of primary treatment units for settleable solids and grease removal will be observed and reported.

In meeting the primary objective above, several component studies will be conducted.

1. Study of the effect of variations in retention time and mixed liquor solids levels on organic removal and waste sludge quantities. Temperature effects will also be observed.
2. Evaluation of harvesting waste activated sludge solids for use as a feed supplement.
3. The nitrogen balance and process factors affecting it will be studied.
4. The performance of standard design circular settling and channel sedimentation will be evaluated.
5. Observations of velocity profiles under differing aeration patterns will be conducted.
6. Evaluation of modes of operation best suited to the hourly and daily flow variations to achieve economic benefits while maintaining optimum effluent quality.

PROCESS DESCRIPTION

The primary wastewater flows are from the hog and beef kill in-plant catch basins. Additional plant flow is received from other processing areas. Table 1 lists some of the characteristics of the wastewater flow. The values are typical of packinghouse wastewater as noted in the Meat Industry guide(4), by Rohlich(5) and Steffen(6). The major component of the increase in dissolved solids is chloride content. Some limited total nitrogen data yields values of approximately 1.0 to 1.2 lbs. of nitrogen/ 1000 lbs. live weight. Ammonia nitrogen concentrations of 7 to 16 mg/l have been determined.

The meat packing operations are normally on a 5-day week, one-shift schedule. Typical weekday and weekend flow patterns are shown in Figure 1. Flows have varied from 1.7 to 3.4 mgd on processing days.

Table 1. CHARACTERISTICS OF WASTEWATER FLOW

Characteristic	Range mg/l	Median mg/l	lbs/1000*
BOD_5	900-2600	1450	14.8
COD	2000-4900	3100	
Grease	200-800	520	5.3
Suspended Solids	600-1800	1130	11.5
Dissolved Solids	3400-6000	4700	
(Water Supply - T.D.S. - 1100 mg/l)			
pH		6.8	
Temperature		89°F	

- - - - - - - - - - - - -

Live Weight (1000 lbs)	1300-2700	2200	
Avg. Daily Flow	1.7-3.4 mgd	2.7	1230 gal/1000 lw

* Based on 2.7 mgd flow rate and 2,200,000 lbs live weight.

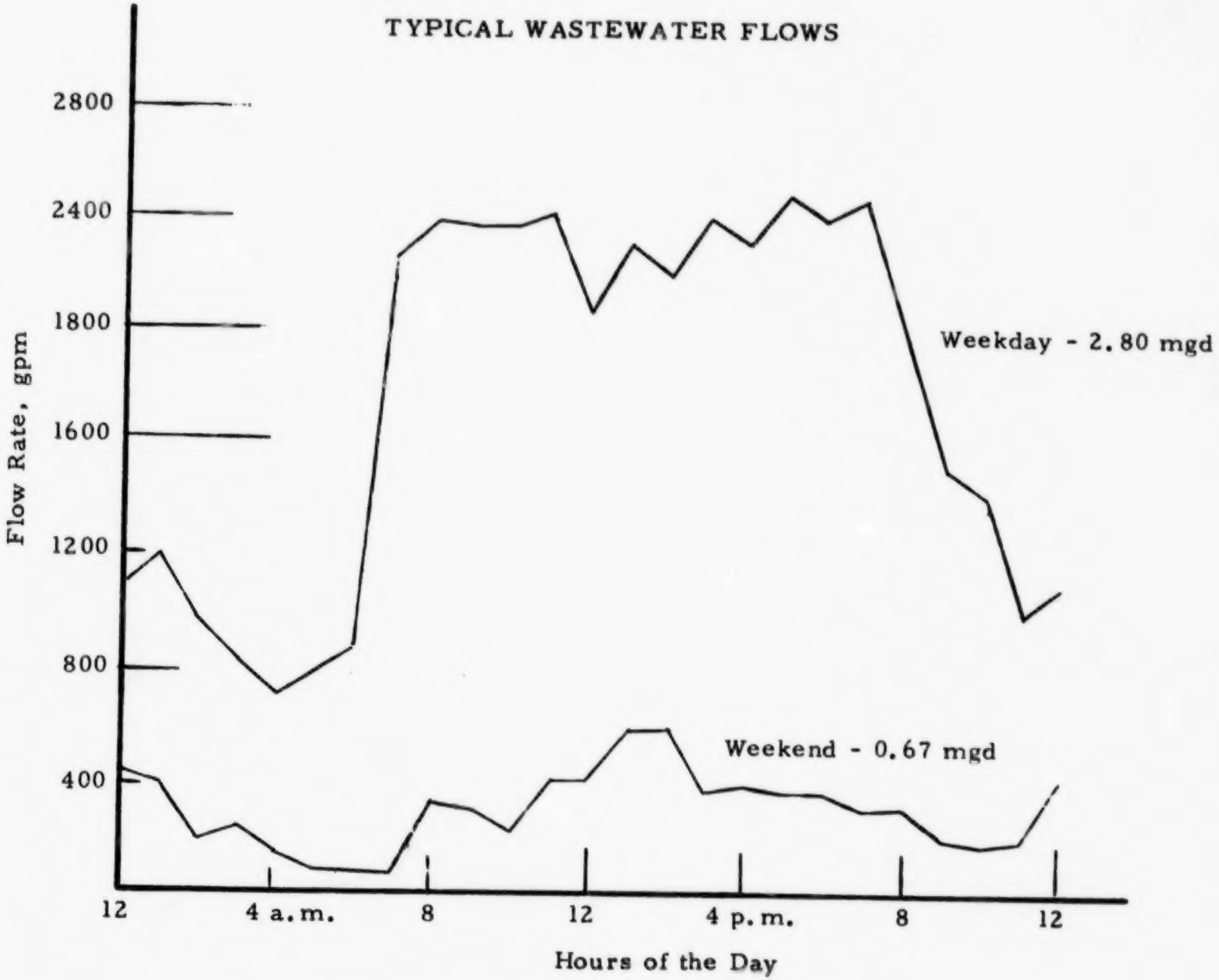


Figure 1. Typical wastewater flows

A schematic plant flow diagram is shown in Figure 2 and an overall plant view in Figure 3. Based on in-plant studies noted earlier, a flow range of 3.25 to 3.50 mgd and a BOD loading of 38,000 lbs were used for design. BOD loadings of 6000 to 10,000 lbs/day were predicted for weekend operation. Actual flows and BOD loadings received to date have been generally lower than the predicted design flows.

The individual plant units are shown in Figures 2 and 3 and listed in Table 2. The bar screen is hand cleaned and receives the total gravity flow from the plant before it is pumped to flow through the treatment units. Both constant and variable speed pumps are used to match the inflow to the treatment plant.

At design flow rates, the aeration compartment provides a 12-minute contact time. This compartment serves the dual purpose of grit separation and aiding in grease separation. The settling compartment or catch basin provides a 42-minute detention time at design flow. Tubular conveyors were installed to remove settleable solids. It is understood that this is the first installation for this purpose. Collector flights convey the floated grease to the discharge end of the basin. An overhead skimmer moves the grease into a trough equipped with a screw conveyor for disposal to a grease hauling unit.

The total effluent flow from the catch basin passes through an 18" Parshall flume and is divided to flow in the relative amounts desired to each aeration channel. The influent to each channel is introduced at two points 225 ft from the north end of each channel. See Figure 3. Each channel (40' x 6') has a capacity of 3,500,000 gallons. The overall north-south length is 1050 feet. Using an average design flow of 3.25 mgd, the channel detention time would be 52 hours and the volumetric BOD loading 24 pounds of BOD per 1000 cubic feet at approximately 22,000 lbs of BOD applied to the channels. For mixed liquor solids concentrations of 1500 and 3000 mg/l, the loading factors would be 0.25 and 0.12 respectively.

The east aeration channel is equipped with 12 mini-magna rotors (Lakeside), 27-1/2" in diameter and 15' in length each. This provides a total rotor length of 180 feet. The rotors are normally operated at 93 rpm and can be immersed up to 10.5 inches under plant conditions. The pounds of oxygen transferred per foot of rotor increases with speed and immersion depth. The approximate rating of the above units at zero dissolved oxygen in tapwater (@ 20°C) are 3.9 pounds of oxygen per hour per foot of rotor for the speed and immersion noted.

The west aeration channel has twelve 42" diameter magna rotors (Lakeside). Total rotor length is 180 feet. These units are normally operated at 68 rpm and can be immersed up to 10.5 inches currently. For these conditions, the units are rated at 4.8 pounds of oxygen per hour per foot of rotor at zero dissolved oxygen in tapwater (@20°C). The rotors provide the velocity to maintain the solids in suspension.

In addition, each channel has one 50-hp and two 20-hp floating aerators (Richards). The 20-hp units are each rated at 1400 pounds of oxygen per day and the 50-hp unit at 3000 pounds of oxygen per day. Both ratings are at zero dissolved oxygen and in tapwater (@ 20°C).

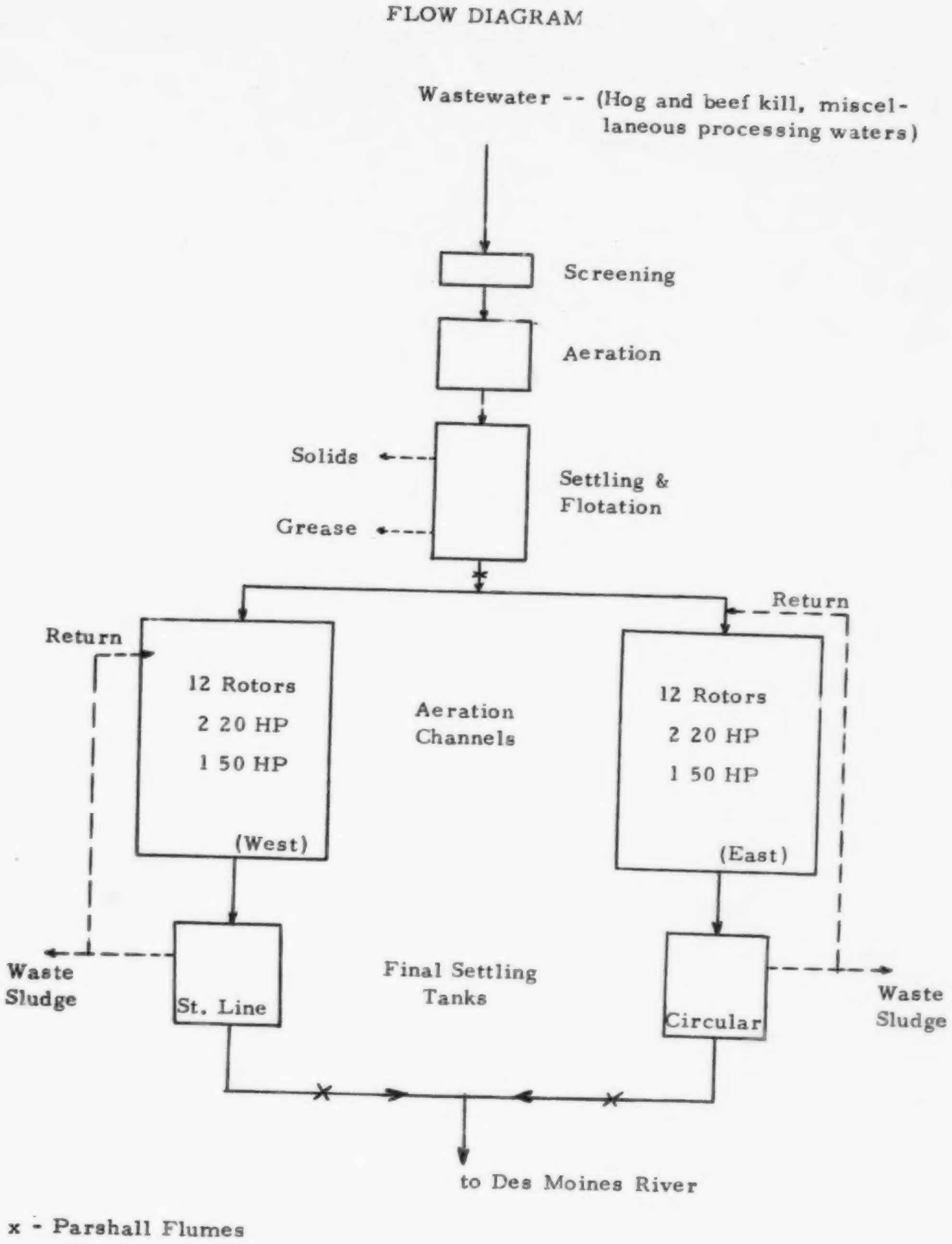


Figure 2. Schematic flow diagram

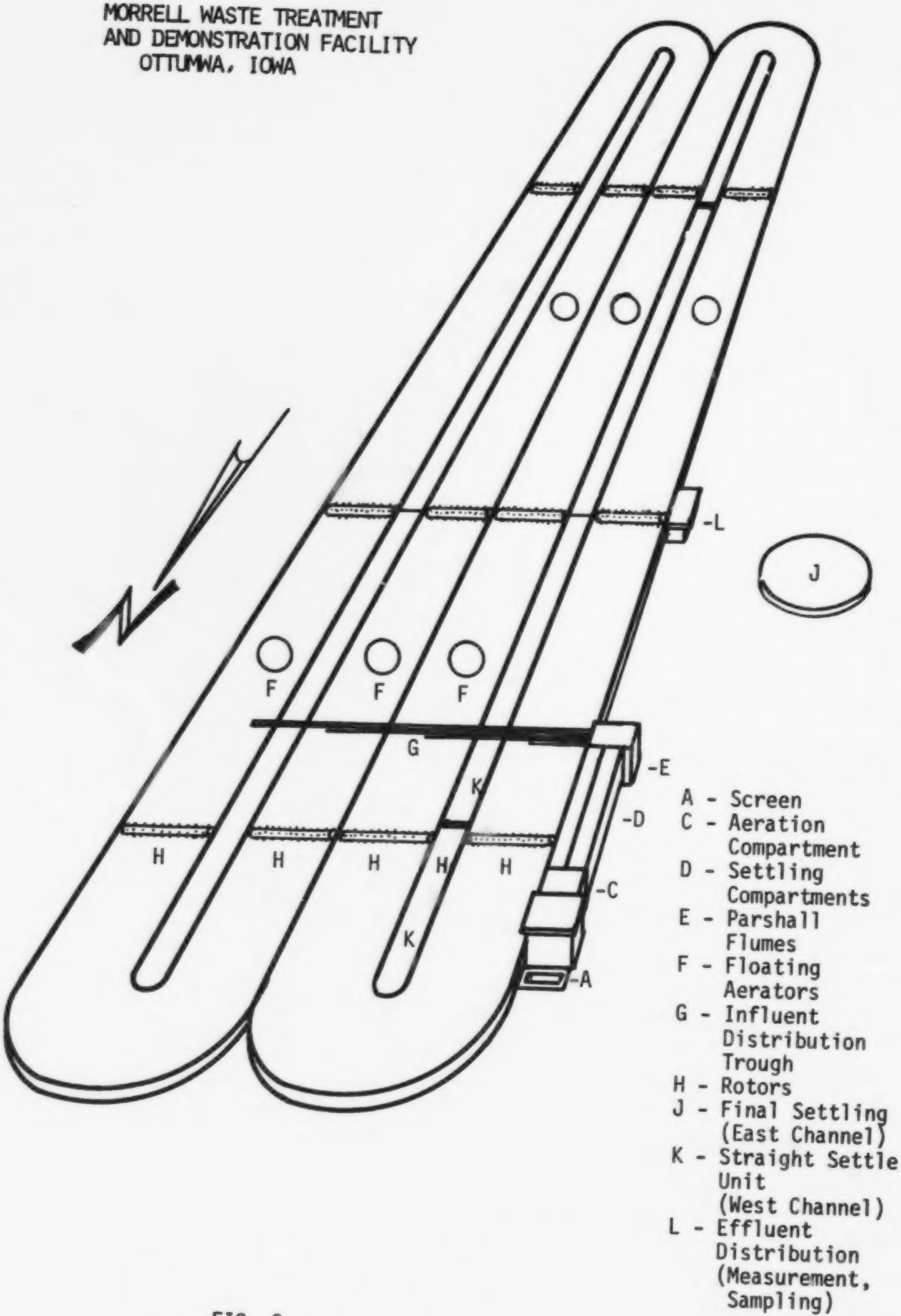

MORRELL WASTE TREATMENT
AND DEMONSTRATION FACILITY
OTTUMWA, IOWA
N
-L
J
F
F
F
G
-E
K
-D
H
H
H
H
H
-C
K
-A
A - Screen
C - Aeration Compartment
D - Settling Compartments
E - Parshall Flumes
F - Floating Aerators
G - Influent Distribution Trough
H - Rotors
J - Final Settling (East Channel)
K - Straight Settle Unit (West Channel)
L - Effluent Distribution (Measurement, Sampling)

FIG. 3

Table 2. PLANT FEATURES

Bar Screen	1.4 inch openings
Aeration compartment	21 x 20 x 9 (28,000 gallons) Air supply - 150 cfm
Settling compartment (Grease flotation)	20 x 100 x 6.5 (97,000 gallons)
Aeration channels (2)	40' wide; 6' water depth Overall st.-line length - 1050' Volume (each channel) - 3,500,000 gallons
Straightline settling unit	16 x 475 x 6 (342,000 gallons) Area - 7600 sq. ft.
Circular settling unit	58' dia; 9.0' depth (178,000 gallons) Area - 2640 sq. ft.

Aeration equipment	East Channel - 12 mini-magna rotors 27-1/2" dia, 15' length West Channel - 12 magna rotors 42" dia, 15' length Each Channel - 2 - 20 HP and 1 - 50 HP floating aerators
Flow measurement	Parshall flumes - total influent, settled effluent from each
Composite samplers	Plant influent and primary effluent; settled effluent from each channel

Summary of rated oxygen transfer capability: (Manufacturer's rating)

	East Channel	West Channel
Rotors	16,800 lbs/day	20,700 lbs/day
Floating Units	5,800	5,800
	22,600 lbs/day	26,500 lbs/day
Total Capacity (Zero D. O., Tapwater @ 20°C)		49,100 lbs/day

Return sludge combines with the influent flow to the east aeration channel at point E in Figure 3. In the west aeration channel, the return sludge is pumped into the channel near point A (Figure 3), 50 feet south of the north end of the channel. At present, some of the solids settled out in the straightline settling unit are re-suspended and directed into the aeration channel through wall openings.

The mixed liquor from the east aeration channel discharges to an overflow weir trough located in the channel and flows to a 58-foot diameter circular settling tank (J). At one-half the total design flow (1.62 mgd), the detention time is 2.6 hours and the overflow rate 600 gpd/ft^2. The weir loading is 9600 gpd/lineal foot.

The effluent from the circular unit flows to building L (Figure 3) where the flow rate is determined and a composite sample is taken. The flow then combines with the flow from the west aeration channel and flows to the Des Moines River. Chlorination for disinfection can be conducted at this location.

As noted above, the settled solids are pumped to point E (Figure 3) where they are combined with the influent as return sludge. If sludge is to be wasted, it is pumped to the wet well at point A where it can be dewatered, disposed of directly or allowed to pass to the catch basin and be processed with the settleable solids.

The mixed liquor from the west aeration channel flows through ports at the north curved end of the channel into the straightline settling unit (K). An effluent overflow weir trough is located at the south end (near rotor row by building L) of the 475' long settling unit. The unit is 16 feet wide and 6 feet deep. At one-half the design flow (1.62 mgd), the detention time is 5 hours and the overflow rate is 210 gpd/ft^2. The weir loading is 10,000 gpd/lineal foot. The clarified effluent flows to building L.

At present a 15-foot cage rotor and a periodic flow reversal are used to prevent the accumulation of settled sludge solids beyond the 44' collector flight path which terminates north of the rotor in the straightline. The sludge hopper is at the north end of the unit. Sludge can be wasted from this hopper similar to the procedure for the waste sludge from the circular unit. Return sludge is as noted above. During the flow reversal period, there is no effluent flow from the west aeration channel.

OPERATIONAL EXPERIENCE - MECHANICAL

Plant Inter-relationships

During the early months of operation, work continued in the processing area on connections to the wastewater treatment plant. Additional in-plant control measures were being developed and installed i.e. a hydra-sieve for hair removal. Several cases of discharges of excess or problem waste materials occurred. Examples include acid washing material, excess grease, blood, hair, toe nails and tripe. Many of the cases were traced to problems with in-plant catch basins, valves, drains and various in-plant flow systems.

Typical treatment plant difficulties resulted such as clogging of piping, pumping problems and damage to mechanical equipment. The hand cleaned bar screen installation required additional operator time as a result of some of the discharges.

The importance of co-operation and correlation of operations was continually stressed and improvements have developed. This is not a unique experience with industrial waste treatment but again demonstrates the need for a close working relationship with product operations and wastewater treatment.

Primary Units - aeration, settling, flotation

The conveyors have not performed as well as desired. Significant amounts of water are withdrawn with the settled solids. A tunneling effect has been observed. Some internal modifications are being tried to improve the solids removal. Land disposal is the current solids handling procedure.

During winter operation, the chain drive mechanism froze. The chain drives were covered with metal shields and heating units installed to prevent freezing.

Large amounts of water were associated with the grease skimmings from the catch basin. Staggered slots were then cut in the flights to allow water to escape as the flight rose to the screw conveyor trough. This has improved the quality of grease removed from the basin.

One thousand gallon cylindrical grease hauling tanks, with overflow shut-offs and steam heaters, were fabricated for continuous grease removal. The grease is returned to the processing plant for recovery.

Aeration Channels

Cage type rotors were installed initially in the East channel. It was understood that this was the first installation of the 15 foot length unit. Various difficulties developed during the first year of operation (Nov. 1969--Nov. 1970). Some of the problems included leaking seals, loose bolts, bearing difficulties, etc. Cracking of the blades was observed. The blades were tested and it was reported that they were cracking due to metal fatigue. Some of the lost blades damaged electrical conduits.

Various new blade shapes and welding techniques were tried to no avail. It was decided that the 12 cage rotors would be replaced (by Lakeside) with 12 mini-magnas of a new design (Nov.-Dec. 1970). These units have functioned reasonably well.

There were several problems with the initial operation of the magna rotors also. One of the difficulties was moisture getting into the motors. Motor covers were constructed to protect the units and they have operated since the change. Some of the rotors broke at the stub shaft weld. New welds were made and they have been satisfactory to date.

Considerable icing problems have occurred during the two winters of operation. The catwalks were constructed adjacent to the rotors and the upper most elevation of the rotors is near the catwalk surface. This results in considerable splashing onto the catwalks.

Ice built up on and adjacent to the catwalks and rotors. Ice chunks that would break loose would damage the rotor blades. In addition, the build-up of ice made working conditions very dangerous in the areas near the rotors.

Two types of splash shields were developed to control the icing problem. One shield is curved to essentially cover the typical upward spray pattern of the rotor. These units have worked quite well, although they are quite expensive. A flat vertical splash shield was also used. It is less effective but provided some help. It is anticipated that other measures will be developed during the spring and summer to prevent icing conditions in the future. One consideration will be relocation of the catwalks.

Another icing complication occurs during weekend operation with low flows. The long liquid retention time, extensive spraying and large air-water interface permits the fairly rapid lowering of the liquid temperature to freezing conditions. Condenser waters have been directed to the treatment plant to help prevent or minimize icing conditions.

The operation of the floating aerators has also resulted in some difficulties. The aerators were added to provide additional aeration capacity and there was no provision for mounting them. Some experimentation with wall mountings and cables was necessary to obtain a reasonably secure installation.

The cone on each of the 50 hp units collapsed after about six months of operation. The units are normally utilized with greater depths and distances from walls and other units. Richards of Rockford, Illinois, redesigned and replaced the cones and they are now in operation.

Straightline Settling Unit

This unit, as described earlier, is 475 ft. long, 16 ft. wide and 6 ft. deep. It has a 44 ft. long flight collector and a sludge hopper on the influent end. The detention time and overflow rates are as follows:

Flow mgd	Time hours	Overflow rate gpd/sq. ft.
1.0	8.3	130
1.5	5.5	196
2.0	4.1	260

It was intended that two of these units would operate alternately. In early operation, one unit was tried. The cage rotor was installed to resuspend the solids that settled to the floor beyond the collector. This did not function satisfactorily. Mr. Ahrens and others developed a flushing concept. A door into the west aeration channel was installed at the south or clarified effluent end of the settler. This door would be opened periodically (manually or on a time clock basis) and the flow reversal along with the cage rotor would resuspend the solids and discharge them to the channel via the wall ports. Some of the settled solids would be removed via the collector and hopper as desired.

This system was not functioning well at the time of this report. Considerable turbulence develops in the region of the effluent weir trough and solids are carried over the weir.

This unit is being studied and changes will be made in the next two months as a portion of the processing plant will be closed. Some ideas being considered are longer flights with a shorter overall tank length, abandon the straightline unit and install a conventional settler, improve the flushing door seal, etc.

PROCESS PERFORMANCE

Table 3 presents some of the early performance experience of the primary units. Median values along with the range of values are presented. It can be noted that with the exception of grease removal, the units are performing better than the design predictions based on pilot unit results.

The aeration compartment has a 12 minute contact time at design flow. The settling unit or catch basin has the characteristics shown in Table 3.

The data presented in Table 3 represent winter operation. An improvement in grease removal is expected. The change in the flight collectors has resulted in better qualitative grease removal. Removal data since the change is not available at this time.

Table 4 presents some of the performance experience to date of the secondary units. Table 5 presents a summary of the operational characteristics of the secondary units.

Table 3. Performance of Primary Units

Characteristic		Raw	Primary Effluent	Percent Removal Observed	Percent Removal Predicted
Suspended Solids	(Median) (Range)	1130 mg/l (600-1800)	640 mg/l (300-1350)	43	40
Grease	(Median) (Range)	520 (200-800)	320	39	65
BOD_5	(Median) (Range)	1450 (900-2600)	900 (400-1400)	38	31

Settling Unit (Primary)

Flow	Time	Overflow rate
2.0	70 min.	1000
2.7	52	1350
3.5	40	1750

As noted in the earlier discussion of operational experience, there was a lot of difficulty in getting the aeration system operable. Most of the data presented represents three to five month's of operation under variable conditions of flow, loadings and solids levels. The data is generally from the winter months of November through March.

Each side of the plant operated essentially as a separate secondary treatment unit receiving an identical influent. The east aeration channel operated with the circular unit as its final settler. The median total unfiltered BOD (75 mg/l) from this side meets the effluent criteria of the state. Sixty-five percent of the values were below 100 mg/l. The median value results in an overall plant percent BOD removal of 95 percent. The filtrate BOD of 22 mg/l yields a 99 percent removal rate. Ninety-five percent of the filtrate values meet the effluent criteria.

Overall percent COD removals are 90 percent based on total COD and 94 percent based on filtrate COD values. The median effluent suspended solids concentration was 120 mg/l with a range of 10 to 600 mg/l.

Table 4. Performance of secondary units

		East Channel	West Channel
		(Median values)	
BOD_5	(Total)	75 mg/l	320 mg/l
	(Filtrate)	22	12
COD	(Total)	300	1350
	(Filtrate)	185	140
Suspended Solids		120	1050
Grease		18	77
(Limited data)			
NH_3 - N	(as N)	31	45
PO_4	(Total)	69	85
	(Soluble)	53	55
Chlorides		2100	2100

Table 5. Operational Characteristics - Secondary Units

Aeration Tanks

MLSS Range	1000-1600 mg/1 (2000-2600 limited period)
Dissolved Oxygen	0.5± mg/1 (Higher on weekends)

	I	II	III
Flow, mgd	2.0	2.7	3.5
Applied BOD_5 (900 mg/1), lbs	15,000	20,000	36,000
Nominal detention time, hrs	84	62	48
Volumetric loading, lbs/1000 cu. ft.	16	21	28
Based on solids under aeration (loadings)			
MLSS - 1500 mg/1, lb/lb	.17	.23	.30
MLVSS - 1200 mg/1, lb/lb	.21	.29	.37
Sludge Age (SRT), days[1]	6	4	3

[1] Based on the reciprocal of the loading factor (Based on sludge wasting--8-11,000 lbs/day, 8-10 days)

Final Settling Units

	Flow mgd	Detention Time hours	Overflow Rate gpd/sq.ft.
Straightline:	1.0	8.3	130
	1.5	5.5	196
	2.0	4.1	200
Circular:	1.0	4.3	380
	1.5	2.8	568
	2.0	2.1	758

Throughout most of the period the east aeration channel D. O. levels were quite low, near 0.5 mg/1. Sludge bulking was suspected and mixed liquor samples were studied. Large numbers of filamentous bacteria were observed. The mixed liquor also contained from 11 to 14 percent grease and pieces of hair were observed. These conditions prevented continued optimum solid-liquid separation. It is anticipated that improved grease removal in the primary unit, the installation of hair removal equipment and improvements in the aeration system will result in significant improvements and more consistent performance from the east secondary treatment unit.

The performance of the west secondary treatment unit from a total BOD, total COD and suspended solids viewpoint was poor. This was primarily the result of the inadequate performance of the straightline settling unit. Considerable quantitites of solids were lost over the effluent weir due to the excessive turbulence in the areas adjacent to the effluent weir. This was largely due to the fact the openings in the walls did not seal completely when the doors were closed after the flow reversal periods described earlier.

The total BOD removal averaged 70 percent with only 10 percent of the values meeting the effluent criteria. The total COD removal averaged 57 percent. The filtrate BOD median value of 12 mg/1 yields a 99 percent BOD removal. Ninety-eight percent of the filtrate values meet the effluent criteria. The filtrate BOD and COD values are lower in the west unit. This is due to the higher rate of oxygen supplied to the west aeration channel with the magna rotors. The oxygenation rates of the mini-magnas (east channel) are estimated based on the cage rotors and it would appear that the estimates may be high. Hence the difference in oxygenation capacity would be greater than noted earlier.

The median suspended solids value was 1050 mg/1 with a range of 50-1800 mg/1. These high values indicate the true difficulty with the straightline unit. In addition to the total BOD and COD results noted above, the high solids carryover is responsible for the much higher effluent grease concentration.

The mixed liquor from the west aeration channel was also studied and found to contain filamentous bacteria, grease and pieces of hair. The dissolved oxygen levels in the west channel were also in the 0.5 mg/1 range. Some settling column studies indicated the effluent solids levels would be similar to the circular unit and marked improvements in effluent quality would be effected with improvements in the physical flow aspects of the straightline settling unit. Improvements in grease and hair removal and expanded aeration capacity will also improve the west unit performance.

Much of the data discussed above was obtained at flow rates from 1.5 to 2.7 mgd and MLSS levels between 1000 to 1600 mg/1. The limited nitrogen and phosphorus data was obtained in March. The increase in NH_3 - N through the plant is due to the deamination of amino acids from protein breakdown and the limited nitrification at the low temperature and D.O. conditions during this period of operation. The high chloride concentration interfered with the nitrate test procedure being utilized. It is anticipated that nitrate data will be obtained during the remainder of the study period.

Typical loadings, detention times and solids retention times (SRT) are reported for three conditions of operation experienced to date. (See Table 5)

Dr. Halvorson proposed the use of the waste activated sludge as a feed supplement. His research findings indicated a high protein content and he estimated a quantity of 6 to 8,000 lbs/day.

Limited data to date indicate sludge wasting quantities from 8 to 11,000 lbs/day while operating at the 1500 mg/l MLSS level. Some qualitative determinations have been made. The mixed liquor solids have contained from 28 to 45 percent protein, 11 to 14 percent grease and are 80 percent volatile. Some pieces of hair have been observed in the dried sludge. Laboratory feeding experiments are being conducted. The grease and hair content is of concern. It is expected that much of the hair will be eliminated in future operations and that the grease content will be decreased.

Studies will be conducted to compare the economics of dewatering and drying for solids recovery versus operating at a minimum sludge wasting mode and utilizing land disposal.

SUMMARY

1. From data to date, it would appear that the treatment plant will consistently meet the design goal of organic removal of BOD with necessary alterations in overall aeration capacity and sedimentation changes in the west secondary unit operation.

2. Various equipment and design approaches (aeration, settling, etc.) have been evaluated and the results should aid designers who may consider using similar plant features in their designs. Further plant revisions will expand this area.

3. The importance of cooperation and coordination in creating a saleable product and simultaneously meeting environmental control needs (wastewater treatment) was again demonstrated.

4. The conclusion of the post-construction study will provide additional process performance data, information regarding possible sludge utilization and economic comparisons of this method of packinghouse waste treatment.

REFERENCES

1. Ahrens, G. E., "Morrell Pioneers More Efficient Aeration," Food Engineering, August 1969

2. Guillaume, F., "Evaluation of the Oxidation Ditch as a Means of Wastewater Treatment in Ontario," July 1964, Ontario Water Resources Commission.

3. Halvorson, H. V. et al, "Report--Proposed Packinghouse Waste Treatment Plant Employing a Channel Aeration Process," 1967.

4. U.S.P.H.S., Industrial Waste Guide - Meat Industry, Publication No. 306, 1965.

5. Rohlich, G. A., "Eutrophication and the Meat Industry," 65th Annual Meeting American Meat Institute, October 1970.

6. Steffen, A. J., "Waste Disposal in the Meat Industry - A Comprehensive Review," Proceedings of the Meat Industry Research Conference, March 1969.

SOLID WASTE MANAGEMENT IN THE FOOD PROCESSING INDUSTRY

by Henry T. Hudson*

INTRODUCTION

One of the major problems facing the food processing industry is the proper and economical disposal of increasing quantities of solid waste. Production of processed foods has more than doubled in the past 25 years. In the face of predictions of continued population growth, the production of food must continue to accelerate and will result in corresponding increases in solid waste.

To develop solutions to our solid waste problems in a realistic and systematic way, reliable information on current solid waste generation and management is needed, as are projections for the future. Today I will briefly describe the first comprehensive study of solid waste management in the food processing industry, along with some preliminary results.

GENERAL BACKGROUND OF STUDY

In June of 1968, the then Solid Waste Management Office contracted with the National Canners Association (NCA) for a study entitled "Evaluation of Current Methods and Techniques on Solid Wastes in the Food Processing Industry." The purposes of the contract are (1) to obtain basic information and data on the national, geographic, and seasonal distribution of solid wastes with respect to both the quantity and the character of the wastes; and (2) to obtain descriptions and evaluations of current methods, techniques, and costs involved in the management of the wastes.

The survey covered 3 major areas: canned foods, frozen foods, and dehydrated products. Within these areas, information was collected from processors of fruits, vegetables, seafoods, and specialties. The data gathering phase of the project has been completed, and we expect work on the study to be completed by the end of August. The final report will be published thereafter.

METHODS AND PROCEDURES

Information was obtained through questionnaires and site visits. The detailed questionnaire was designed to collect basic industry

---

*Engineer, Office of Solid Waste Management Programs, U.S. Environmental Protection Agency, Cincinnati, Ohio 45213.

Preceding page blank

data on solid waste management. Over 1,100 copies were distributed throughout the United States and Puerto Rico to member companies of the National Canners Association and the American Frozen Food Institute, and more than 400 questionnaires, each representing an individual plant, were returned. The questionnaires returned amount to an industry-wide coverage of about 1 out of every 7 plants. They represent all sizes of plants and a full range of products and regions. Large plants are more heavily represented than small ones. As a result, about 30% of the total production was covered by the questionnaire survey. Our estimates of industry characteristics were derived from this basic data base that covered about 15% of the plants and 30% of total production.

The site visits to 229 individual plants collected more detailed information than that obtained by the questionnaires. These plants, most of which had previously returned a questionnaire, were selected on the basis of size, geographic location, and product. All of the major canned and frozen commodities were covered. The geographic dispersion of the site visits was quite thorough, with visits being made in every section of the continental United States as well as Alaska.

DISCUSSION

The figures on food residuals used here are all based on values reported in the questionnaire survey by individual plants for amounts of food residuals whose disposition was accounted for (see Appendix). These preliminary figures will doubtless be refined by NCA in their final report, which, in addition, will contain data on nonfood solid waste not covered here.

A simplified mass-flow diagram of the food processing industry indicates the raw products going into food processing (Figure 1). When all of the products processed are considered, the industry's total yearly consumption of raw product is estimated at 33.5 million tons, with roughly 52% being vegetables, 36% fruit, 10% specialties, and 3% seafood.

In processing, the raw product becomes either primary product yield or food residual. The food residuals are essentially gross screenable solids; they do not include such things as dirt and other washings that enter the liquid waste stream without being accounted for. Overall the industry's yield is about 72%, with an average residual of 28%.

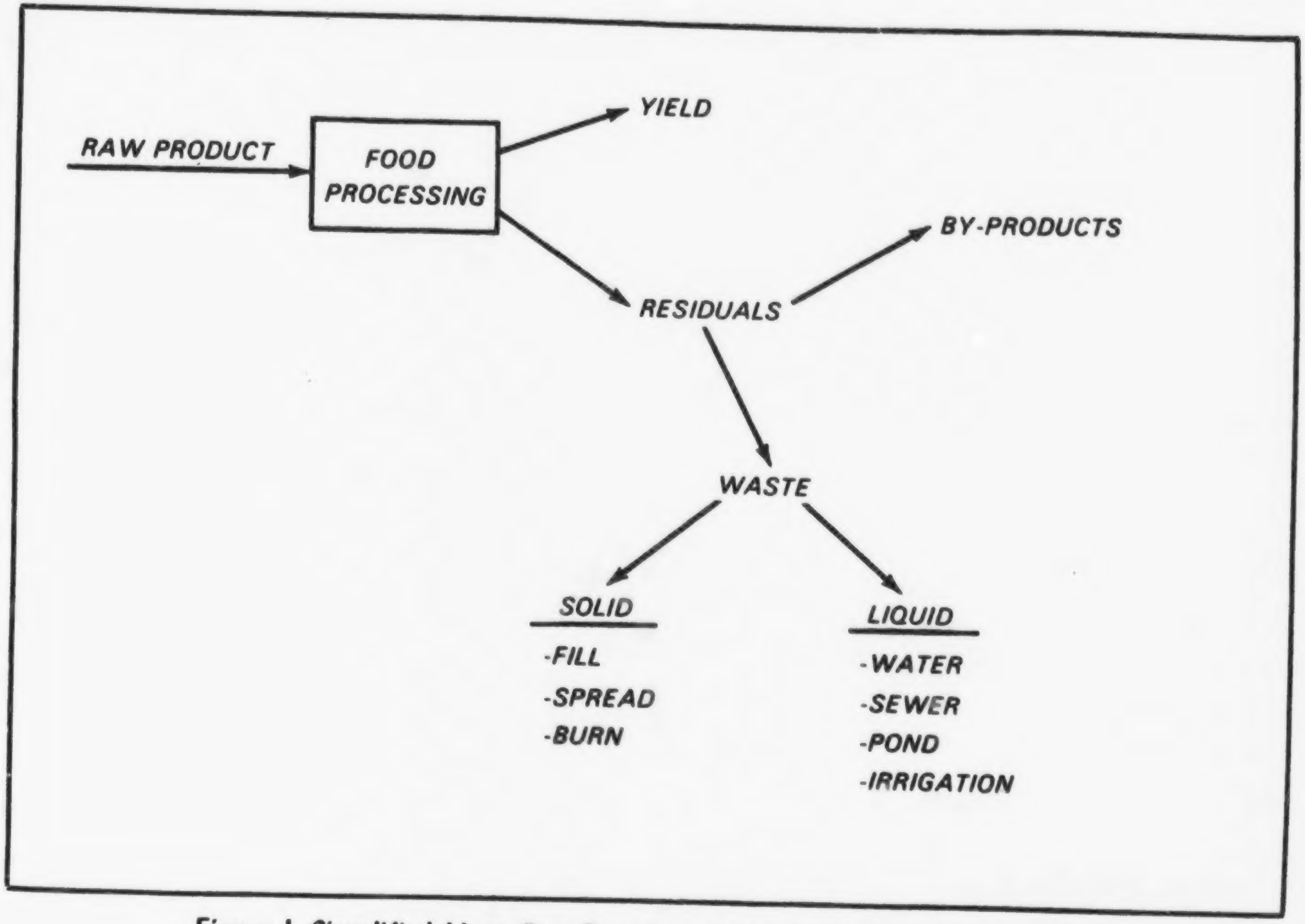


Figure I. Simplified Mass-flow Diagram of the Food Processing Industry.

Percent Residual

Knowing the percent residual from the processing of a raw product is important to the food processor because it represents the part of his raw product that will not be marketable as a primary food product. Knowing this percent allows engineers and planners to estimate the amount of food residual expected from a given plant's operation. They can then properly plan and size waste management systems to handle the anticipated load.

It is erroneous to speak of "average residuals" for the major food product lines. On a histogram illustrating the variation in percent residuals from product to product in the processing of vegetables, the vertical dashed line shows the computed average residual for all vegetables at 26% (Figure 2). The percentages vary, however, from 5 to 10% residuals for tomato processing to between 60 and 65% for corn, with white potatoes producing between 30 and 35%. The other, unlabeled vegetable products also have widely varying rates of residual generation, ranging between 5 and 65%.

"Percent residual" is a very product-specific term and can't be used accurately for general groups of products. If, for example, the average residual of 26% for all vegetables were used to estimate the residuals from corn processing, the error would be over 100%.

The height of each bar in Figure 2 indicates which percent of all vegetable tonnage processed in the United States comes from each vegetable product, e.g., tomatoes are about 40% and corn about 15%. Together, the bars represent all vegetable tonnage processed and include 14 major types of vegetables and one category called "miscellaneous vegetables." These miscellaneous vegetables include ten relatively minor products that account for about 7% of all vegetable tonnage processed.

Clearly, the "big 3" vegetable products are tomatoes, corn, and white potatoes. Overall, the range in percent residuals from fruit is from 5 to 45%, with the average residual at 36% (as indicated by the vertical dashed line in Figure 3).

Citrus fruit (65% of the fruit tonnage processed) obviously dominates fruit processing. Citrus residuals range between 35 and 40%, and pineapple is the only fruit with a higher percent residual. Again, the average residual of 36% for all fruit is not very meaningful. The categories used here include 10 major types of fruit plus "miscellaneous fruit." The latter includes seven products that account for only 1% of all fruit tonnage processed.

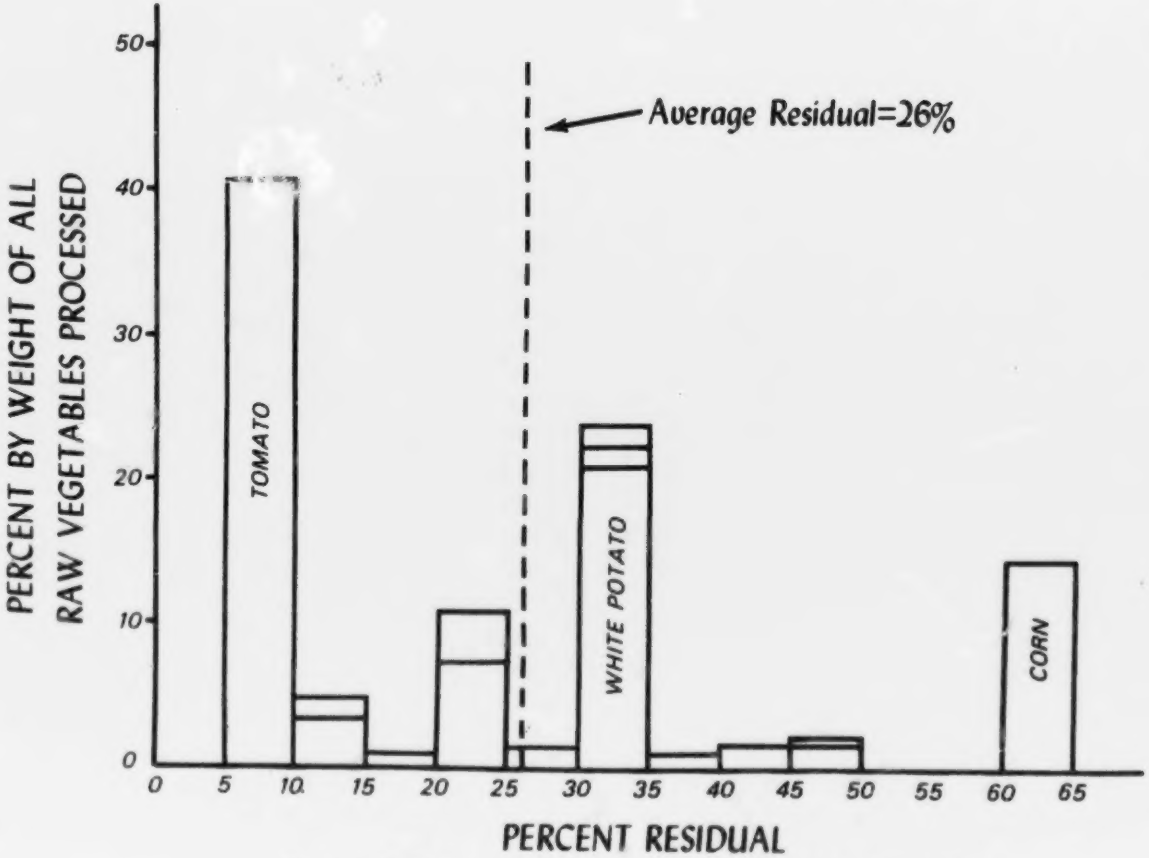


Figure 2. Percent Residuals from Vegetable Processing.

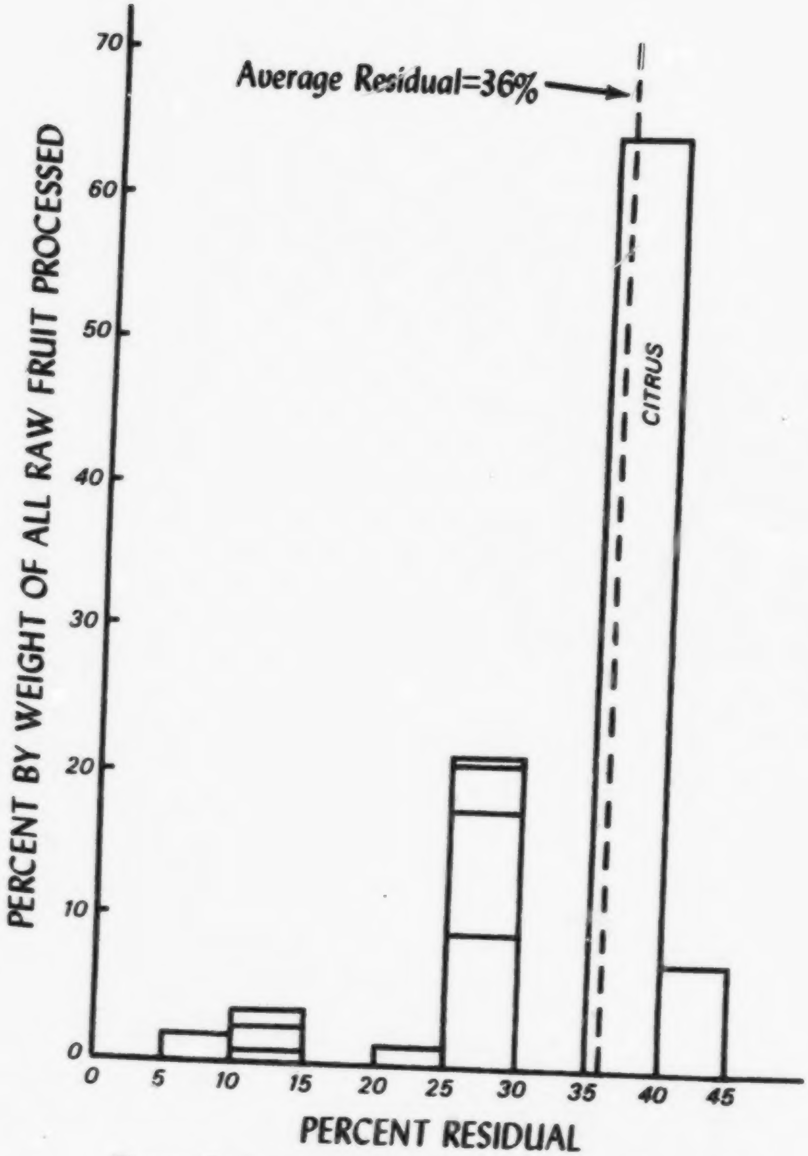


Figure 3. Percent Residuals from Fruit Processing.

The range in residuals for specialty foods is fairly narrow--between 0 and 15% (Figure 4). The differences amoung the three items shown, compared with the average residual of 11% for all specialties, are still significant, however. The "specialty" products are those those such as baby food, TV dinners, soup, stew, spaghetti.

Seafood is by far the most diverse group of all, with residuals ranging between 10 and 90% (Figure 5). This group, which almost defies averaging, illustrates how product-specific residual generation really is. The seven categories used are clams and scallops, oysters, crab shrimp, salmon, sardine, and tuna and miscellaneous seafood. Tuna makes up almost all of the "tuna and miscellaneous seafood" category.

Residuals as Byproducts

The residuals from food processing become either byproduct or waste (Figure 1). About 9.3 million tons of food residuals are generated each year and about 7.3 million tons, 79%, are used for byproducts. The remaining 21%, about 2 million tons, is food waste.

Of the four major product lines, fruit, vegetables, specialties, and seafood, fruit and vegetables respectively contribute 46 and 47% of all food residuals and together account for 93%. The other 7% comes from specialties and seafood, with 4 and 3%, respectively (Figure 6).

The height of each bar indicates which percentage each of the four major groups contributes to all food residuals generated by the various products. The uncrosshatched area shows how much of each product's residuals is used for byproducts; the crosshatched area shows how much is left to be disposed of as waste.

More than three-fourths of the residuals used as byproducts comes from only three products--citrus, corn, and white potatoes, and all but 3% of the residuals used as byproducts are used for animal feed. Other byproducts are charcoal, alcohol, oil, vinegar, and fertilizer.

In the fruit category, 95% of the residual comes from only four products--citrus, pineapple, peach, and apple. The remaining 5% is divided among all other fruit products.

The dominance of only a few products also hold true for vegetables. Three products--corn, white potatoes, and tomatoes--generate 75% of all vegetable residuals. The remaining 25% is divided among 12 other types of vegetables.

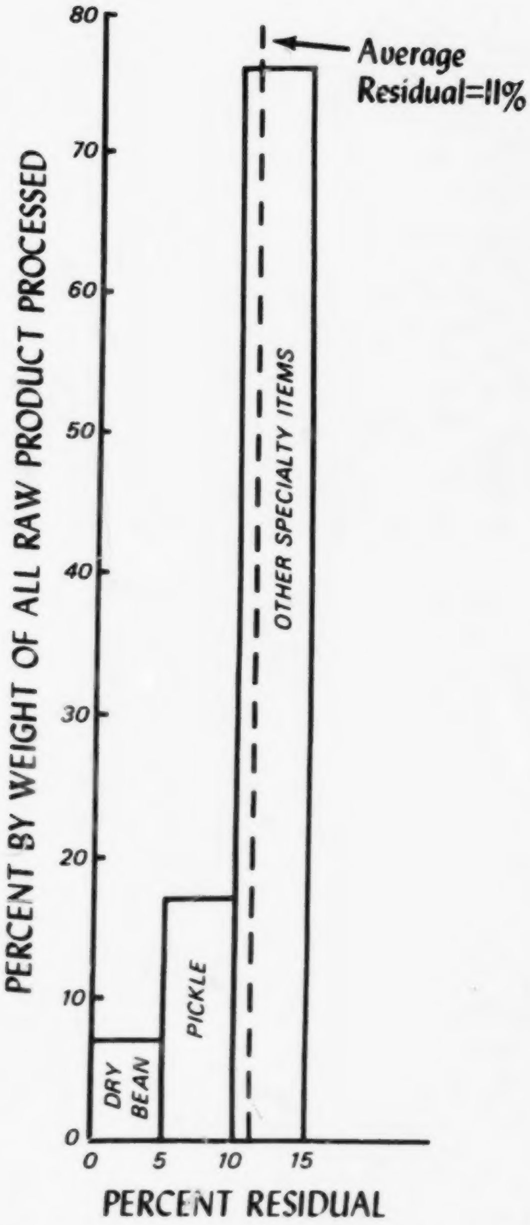


Figure 4. Percent Residuals From Processing of Specialties.

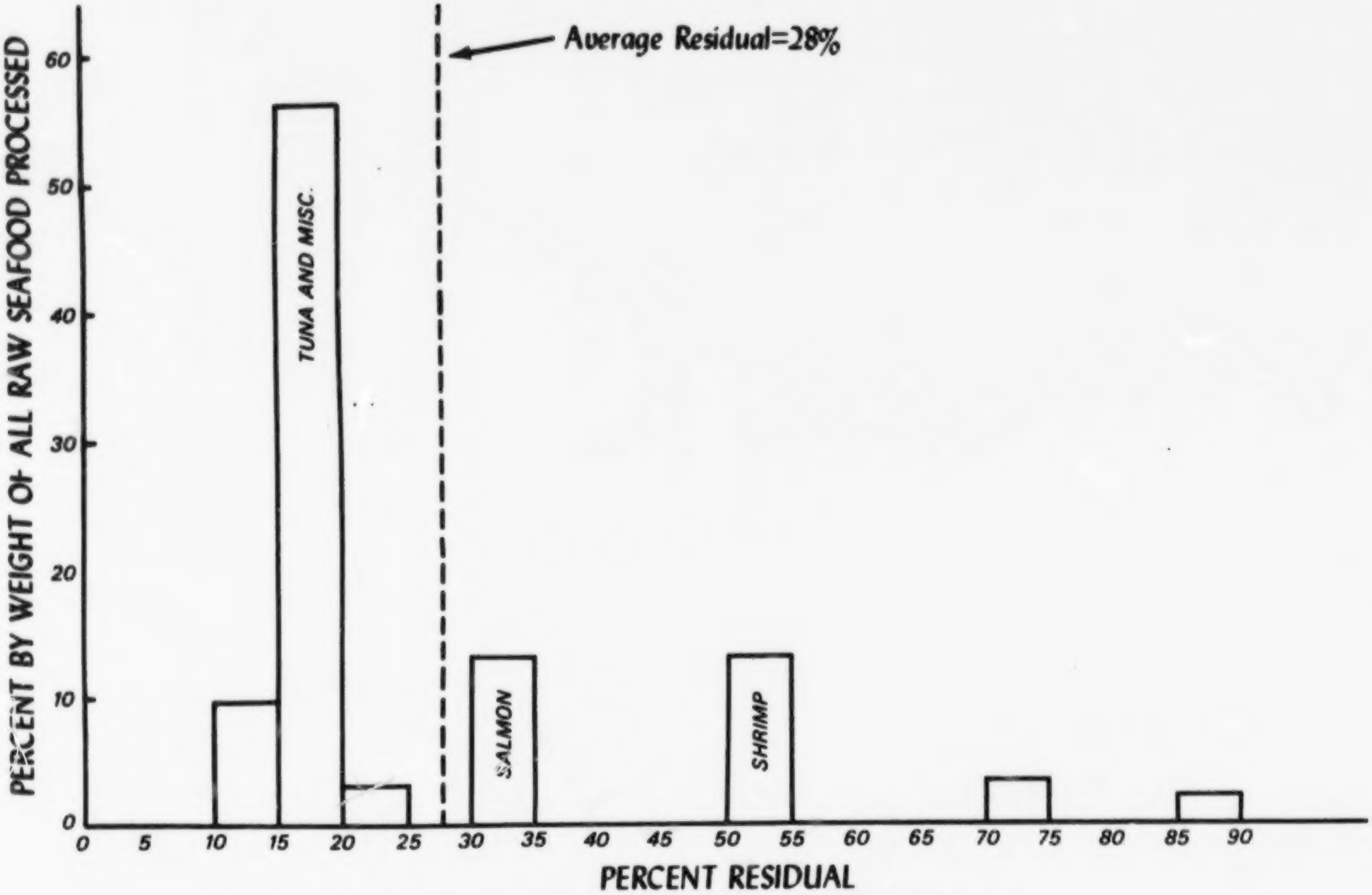


Figure 5. Percent Residuals from Seafood Processing.

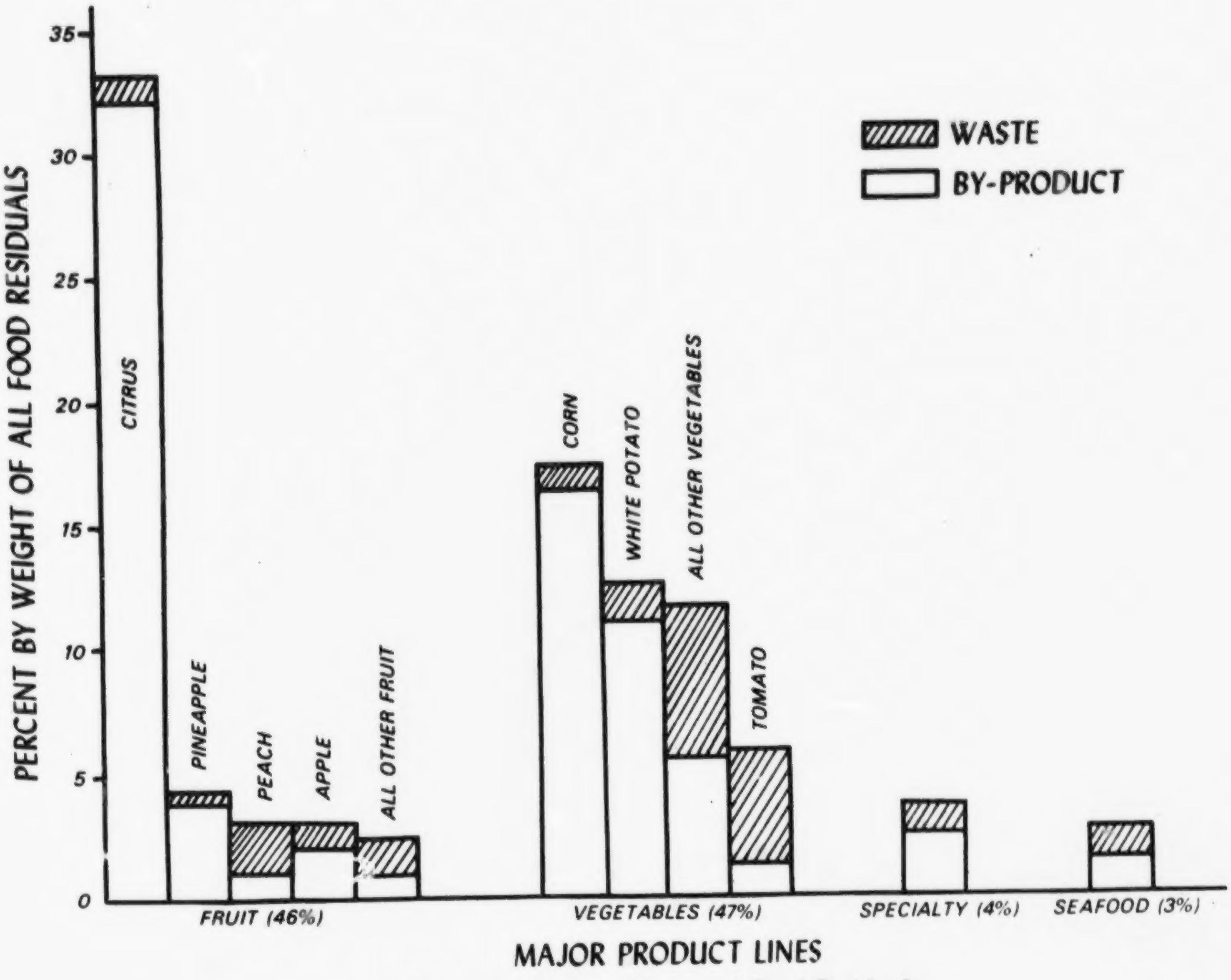


Figure 6. Product Sources of Food Residuals.

Residuals as Solid Waste

Most food residuals are used as byproducts, mainly animal feed; the flow diagram shows that the rest that's left as waste is disposed of as solid waste or in a liquid medium (Figure 1). About 84% of the total 2 million tons of food processing waste generated each year is disposed of as solid waste by filling, spreading, or burning.

The terminology used here is important: filling does not imply covering or compacting and does not necessarily mean sanitary landfilling; spreading is usually done on agricultural land and may or may not include disking; burning refers to materials burned on-site at the food processing plant and usually includes nonfood waste.

The four major product lines are listed in the order of the amount of solid waste they generate--vegetables, fruit, specialties, and seafood (Table 1). The total amount of waste produced by each product and how much of each product's waste is disposed of by the three methods (filling, spreading, or burning) is given in thousands of tons.

Table 1. Tons of Food Residuals Disposed of as Solid Waste (per 1,000 tons)

Product	Amount	Disposal method Filling	 Spreading	 Burning
Vegetable	1,037	467	566	4
Fruit	526	279	246	1
Specialty	93	77	8	8
Seafood	25	13	9	3
Total	1,681	836	829	16

Nearly all the 1,681,000 tons of solid waste is disposed of by filling or spreading. The tons are almost evenly divided between the two methods, and burning is shown to be a relatively minor disposal method.

The total amount of residuals disposed of as solid food waste (about 1.7 million tons) comes from the four major product groups:

62% from vegetables; 31% from fruit; and 7% comes from specialties and seafood (Figure 7).

The height of each bar indicates which percent of all food residuals disposed of as solid waste comes from each product shown.

The four vegetables (tomatoes, miscellaneous vegetables, corn, and white potatoes) that contribute 40% of the total 1.7 million tons and the four fruit products (peach, apple, citrus, and pear) that account for 25% together contribute 65% of all food residuals disposed of as solid waste.

Each of four other vegetables, snap beans, beets, cabbage, and carrots, account for 2 to 4% of the solid waste. The two remaining categories, "all other vegetables" and "all other fruit," represent a total of 14 products. Eight of them produce 1 to 2% of the solid waste and six produce less than 1%.

Residuals as Liquid Waste

Food waste not disposed of as solid waste is disposed of in a liquid medium (Figure 1). The terminology used here also needs explanation. Disposal in "water" means dumping into a stream, lake, bay, or ocean without any treatment although some waste disposed of in this manner is ground up before dumping; in a "sewer" means a public treatment system; in a "pond" means a holding or treatment pond; and "irrigation" is self-explanatory. About 300,000 tons of food waste, 16% of the total 2 million tons, is disposed of in liquid.

The four major product lines are listed in the order of the amount of waste they dispose of in liquid--vegetables, seafood, fruit, and specialties (Table 2). The total amount for each product and how much of each product's waste is disposed of by each method is given in thousands of tons. Nearly all the 319,000 tons is disposed of by "water" and "sewer," and "pond" and "irrigation" are relatively minor disposal methods. Over half of the total tons is disposed of by "water."

Of the total amount of food waste disposed of in liquid, vegetables generate 50%, seafood jumps to second place with 30%, fruit generates 12%, and specialties, 8% (Figure 8).

The height of each bar indicates which percent of all food wastes disposed of in liquid comes from each of the various products. The three biggest contributors within each product line (vegetables, seafood, and fruit) account for 81% of all food wastes disposed of in liquid. Miscellaneous vegetables, white potatoes, and tomatoes account for 41% of the 300,000 tons disposed of in liquid; shrimp,

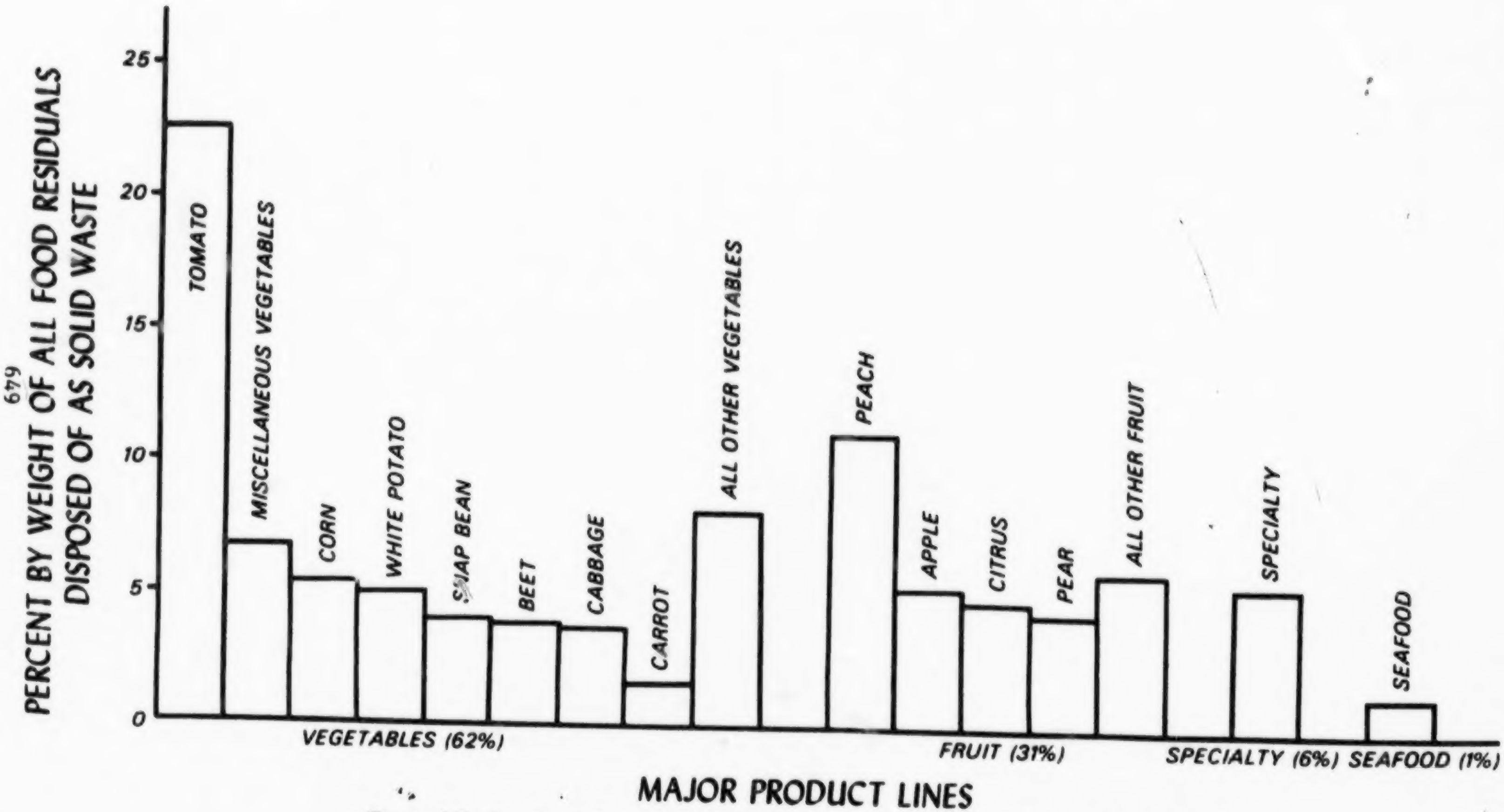


Figure 7. Product Sources of Food Residuals Disposed of as Solid Waste.

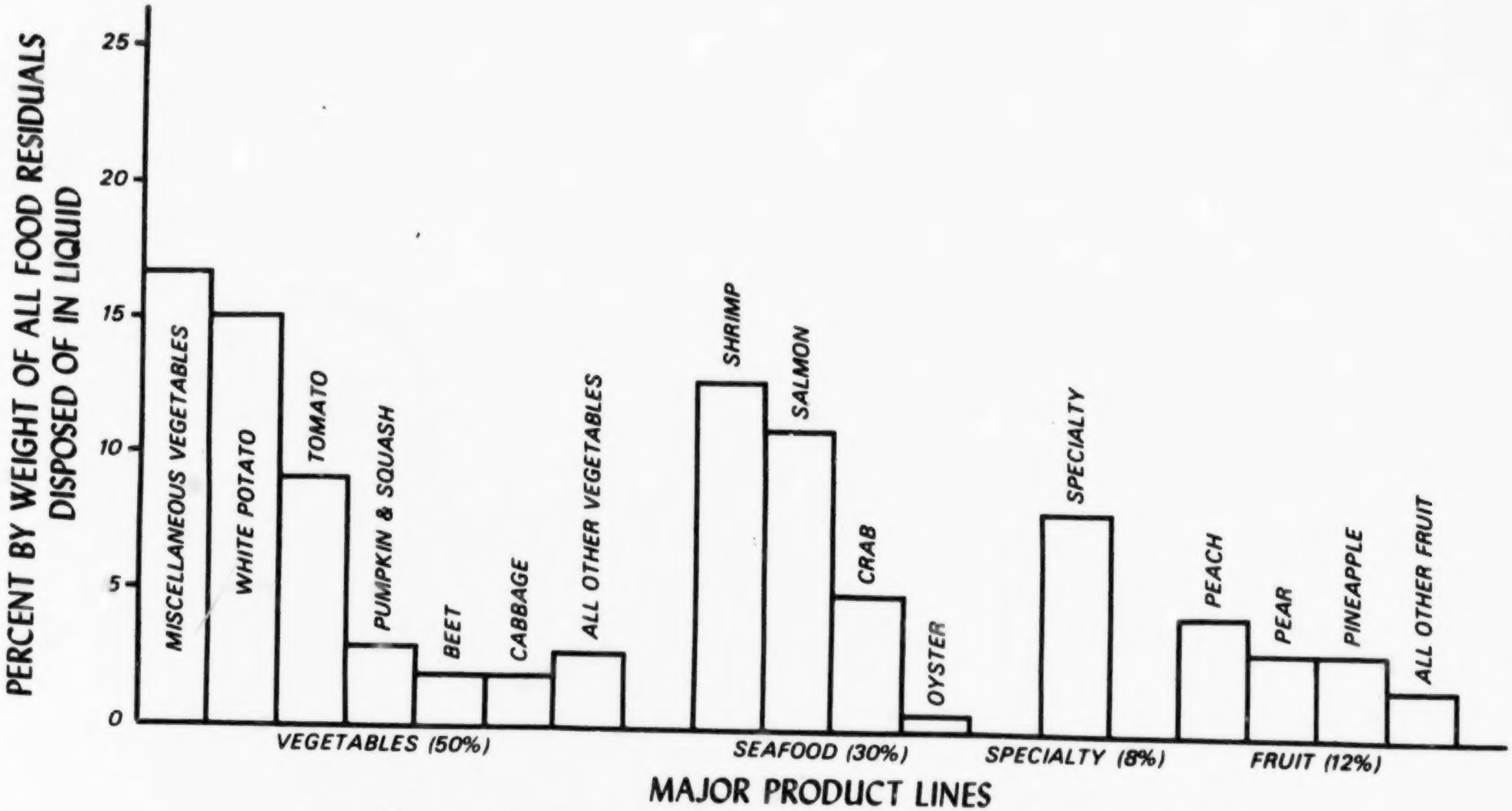


Figure 8. Product Sources of Food Residuals Disposed of in Liquid.

Table 2. Tons of Food Residuals Disposed of in Liquid (per 1,000 tons)

		Disposal method			
Product	Amount	Water	Sewer	Pond	Irrigation
Vegetable	160	63	79	16	2
Seafood	94	82	12	0	0
Fruit	39	31	6	0	2
Specialty	26	0	19	7	0
Total	319	176	116	23	4

salmon, and crab account for 29%; and peaches, pears, and pineapples contribute 11%.

Each of three other vegetable categories, pumpkins and squash, beets, and cabbage, generate between 2 and 3% of the total. In seafood, oysters produce less than 1%.

The remaining categories, "all other fruit" and "all other vegetables," represent eight products that individually also contribute less than 1%.

CONCLUSION

The food processing industry is to be commended for its high degree of residual utilization--79%. Hopefully, additional ways of reusing more types of residuals will be found.

This industry's challenge is to upgrade its methods of disposing of the residual solid waste. Where filling is necessary, it should be done in a sanitary landfill. Open burning should be stopped, as should the discharge or dumping of untreated or improperly treated waste into bodies of water.

This challenge is not easy, nor can it be met overnight. But, to protect and preserve our environment, it is a part of an over-all environmental protection job that can and must be done.

APPENDIX

Using data obtained via the questionnaire survey, NCA developed estimates for the total amount of food residual generated each year in the processing of each food product and also the total for each food product whose disposition was accounted for. When the estimates for each of the two groups are totaled, the results are not the same. It is important to understand how these estimates were made and what the potential sources of error in them are.

Total Food Residuals Generated

Each plant that responded to the survey reported the amount of each raw product it processed per year and the percent yield in the processing of each product. With the use of these data, the amount of food residual by product was calculated for the reporting plants. These amounts were then added to obtain sums of food residual by product for all reporting plants. The sums were then extrapolated to obtain estimates for the industry's total yearly food residuals by product (TFRi).

Total Food Residuals Accounted For

Other data collected from individual plants via the questionnaire survey included the amount of food residual from each product that was accounted for per year as being

1. used for byproducts (by use),
2. disposed of as solid waste (by method),
3. disposed of in a liquid medium (by method).

The quantities reported for each product were added and these sums were then extrapolated to obtain corresponding figures for the disposition of the industry's total "accounted-for" food residual by product. For a given product, the sum of the amounts in each of the disposal/use modes represents the total yearly food residual from that product whose disposition was accounted for (TFRj).

The figures presented in this paper were derived from these calculations, and all of the figures are based on amounts of food residuals whose disposition was accounted for by the individual reporting plants.

Differences in Results

For most of the products, the TFR_i and TFR_j values were not the same. Since, for a given product. TFR_i represents the actual total food residual generated per year and TFR_j represents the total food residual whose disposition was accounted for, then the difference

$$D = TFR_i - TFR_j$$

represents food residual whose disposition was not accounted for. Both positive and negative values for D were obtained.

ΣTFR_i estimates the industry's total yearly food residual for all products at about 10.3 million tons; ΣTFR_j estimates the total yearly food residuals whose disposition was accounted for at about 9.3 million tons. The total net amount of food residuals whose disposition was not accounted for was then approximately 1.0 million tons and hence, the accounted-for residuals constitute approximately 90% of the industry's yearly total.

Sources of Error

A number of potential sources of error in the calculation of values of TFR_i and TFR_j may partially explain the differences observed. The known potential sources include:

1. Reported amounts of raw product processed could be inaccurate.
2. Reported values for percent yield could be inaccurate.
3. Product shrinkage from the loss of moisture generally occurs between the time of delivery and the time of processing.
4. The weight of food residuals accounted for may include the weight of moisture absorbed during processing.
5. Materials entering the waste stream such as leachates, dirt, and washings would not be accounted for.
6. Records of food residuals used as byproducts or disposed of may simply be incomplete.

Representativeness of Data Presented

As was stated, the data presented here are based entirely on the figures for food residuals whose disposition was accounted for: a total of about 9.3 million tons or 90% of the estimated total food residuals generated.

An assumption was made that the unaccounted-for food residuals of 1.0 million tons are distributed in the disposal/use modes in the same manner as the 9.3 million tons that were accounted for. If this assumption is correct, then the omission of the unaccounted-for food residuals does not seriously impair the representativeness of the data presented.

Summary

Extrapolations based on data on food residuals whose disposition was accounted for indicate that the food processing industry disposes of or reuses about 9.3 million tons of food residuals per year; the figures presented in this paper are based on these extrapolations. Other extrapolations based on the amounts of raw products processed and percent yields show that the total food residual generated per year is about 10.3 million tons. Logically, then, the disposition of about 10% of the food residuals generated is unaccounted for. However, the data presented--based on about 90% of the food residuals generated--should be representative of current waste management practices in the industry.

REGISTRATION LIST

WILLIAM L. ALLINSON
Chief Engineer - F.M. & I.C. Division
Carnation Co.
5045 Wilshire Blvd.
Los Angeles, Calif. 90036

CURTIS R. ALLS
Asst. Plant Manager
National Fruit Product Co. Inc.
Box 609
Winchester, Virginia 22601

MELVIN D. ALSAGER
Environmental Control Coordinator
J. R. Simplot Co.
Box 2777
Boise, Idaho 83707

RONALD L. ANTONIE
Manager of Application Engineering
Bio-Systems Division
Autotrol Corporation
5855 North Glen Park Road
Milwaukee, Wisconsin 53209

ADOLPH R. ASTI
Vice President
Redwood Food Packing Co.
P. O. Box 630
Redwood City, Calif. 94063

GERALD R. BABCOCK
Plant Engineer
Stayton Canning Company Co-operative
P. O. Box 458
Stayton, Oregon 97383

DANIEL W. BAKER II
Mechanical Engineering Technician
National Marine Fisheries Service
FisheryProducts Technology Lab.
Gloucester, Mass. 01930

DARRELL A BAKER
Chemist in Charge
Farmland Foods Inc.
Box 403
Denison, Iowa 51442

W. F. BARTELT, JR.
Environmental Control Engineer
Libby, NcNeill & Libby
200 S. Michigan Avenue
Chicago, Ill. 60604

J. CLAIR BATTY
Assoc. Prof. of Mechanical Engrg.
Dept of Mech. Engineering
Utah State University
Logan, Utah 84321

DR. DONALD J. BAUMANN
Prof. of Chemistry
Creighton University
2500 California St.
Omaha, Nebraska 68131

DR. SHELDON BERNSTEIN
President
Milbrew, Inc., 330 S. Mill St.
Juneau, Wisconsin 53039

JOSEPH T. BISHOP
Business Development
Envirotech Systems Inc.
100 Valley Drive
Brisbane, California 94005

ROBERT C. BLACK
Technical Director
The AquaTair Corporation
111 West First Street
Dayton, Ohio 45402

DANFORTH G. BODIEN
Industrial Waste Specialist
Water Quality Office - EPA
501 Pittock Block
Portland, Oregon 97205

CLARENCE L. BOLT
Quality Control Manager
Prosser Packers, Inc.
1001 Bennett Avenue
Prosser, Washington 99350

SIDNEY BOXER
President
Dairy Research & Development Corp.
111 Broadway
New York, N. Y. 10006

JAMES R. BOYDSTON
Chief, National Waste Treatment Research
Pacific Northwest Water Lab - EPA
200 S. W. 35th St.
Corvallis, Oregon 97330

RONALD W. BRENTON
Research Chemist
Great Western Sugar Co.
2652 Stuart
Denver, Colorado

B. E. BRINK
Manager, Technical Department
Sunkist Growers
310 No. Joy St. P. O. Box 640
Corona, Calif. 91720

A. TERRY BRIX
Technical Leader, Chemical Engineering
Battelle-Northwest
P. O. Box 999
Richland, Wash. 99352

DAN BROOKS
National Canners Association
1600 South Jackson Street
Seattle, Wash. 98144

W. R. BROSZ
Environmental Scientist
Green Giant Company
Food Science Dept. (29), Research Center
Le Sueur, Minnesota 56058

CHARLES M. BUCHZIK
Chemical Engineer
Heat & Control, Inc.
225 Shaw Rd.
So. San Francisco, Calif. 95080

ROBERT J. BURM
Sanitary Engineer
Pacific Northwest Water Lab - EPA
200 S. W. 35th St.
Corvallis, Oregon 97330

JOHN R. BURGESON
Sanitary Engineer
Water Quality Office, EPA
911 Walnut
Kansas City, Mo. 64102

GENE R. BUSSEY
President
Life Support Systems, Inc.
5405 Gibson Blvd. S.E.
Albuquerque, NM 87108

HARRY W. BUZZERD, JR.
Director, Communications Ser.
National Canners Association
1133 20th Street, N.W.
Washington, D. C. 20036

ROY E. CARAWAN
Ext. Specialist
Dept. of Food Science
N.C. State University
P. O. Box 5992
Raleigh, N.C. 27607

RICHARD A. CARNES
Chemist
EPA, Solid Waste Mgt. Office
5555 Ridge Avenue
Cincinnati, Ohio 45213

BURTON J. CHERNEY
Sr. Process Engineer
Hunt-Wesson Foods, Inc.
1645 W. Valencia Drive
Fullerton, Calif. 92634

DR. BROOKS D. CHURCH
Senior Microbiologist
North Star Research Inst.
3100 38th Ave. S.
Minneapolis, Minn. 55113

FRED CLAGGETT
Research Engineer
Fisheries Research Board of Canada
6640 N.W. Marine Dr.
Vancouver, B.C., Canada

MAX W. COCHRANE
Sanitary Engineer
Pacific Northwest Water Lab - EPA
200 S.W. 35th St.
Corvallis, Oregon 97330

DR. A. M. COOLEY
Prof. Chem. Eng. Dept.
Univ. of North Dakota
Box 8101 University
Grand Forks, N.D. 58201

DR. WILLIAM CROSSWHITE
Associate Professor
North Carolina State Univ.
6 Patterson Hall
Raleigh, N. C. 27607

JOSEPH W. CYR
Manager - Quality & Environmental Cont.
Western Potato Service, Inc.
Highway 2 West
Grand Forks, N. D. 58201

THOMAS O. DAHL
Sanitary Engineer
Environmental Protection Agency
911 Walnut St.
Kansas City, Mo.

ROGER DAVIDSON
Process Engineer, Sales
Chicago Pump, FMC Corp
2240 W. Diversey Ave.
Chicago, Ill. 60647

GARY W. DAVIS
Sr. Prod. Eng.
B. F. Goodrich Co.
9921 Brecksville Rd.
Brecksville, Ohio 44141

JACK DeMARCO
Deputy Director, Div. of Tech. Oper.
Solid Waste Management Off., EPA
5555 Ridge Ave.
Cincinnati, Ohio 45213

DAVID G. DEVANNEY
Laboratory Technician II
Metro Denver Sewage Disposal Dist. #1
3100 E. 60th Ave.
Commerce City, Colorado 80022

KENNETH A. DOSTAL
Chief, Food Waste Research
Pacific Northwest Water Lab - EPA
200 S. W. 35th St.
Corvallis, Oregon 97330

DR. D. L. DOWNING
N. Y. Ag. Exp. Station
Cornell Univ.
Geneva, N. Y. 14456

DONN R. DRESSELHUYS
Executive Vice President
Autotrol Corporation
5855 North Glen Park Road
Milwaukee, Wisconsin 53209

G. J. DUSTIN
Regional - Mfg. Mgr.
A. E. Staley Mfg. Co.
2200 E. Eldorado St.
Decatur, Ill. 62525

DR. F. A. EIDSNESS
Partner, Black, Crow & Eidsness, Inc.
700 S. E. 3rd St.
Gainesville, Fla. 32601

DR. E. E. ERICKSON
Technical Director
North Star R & D Institute
3100 38th Ave. S.
Minneapolis, Minn. 55406

RICHARD E. ERICKSON
Director, Div. of Community
Environmental Services
Penn. Dept. of Envir. Resources
P. O. Box 2351
Harrisburg, Penn. 17120

DR. PAUL EUBANKS
Sales Engineer
Arthur G. McKee & Co.
10 S. Riverside Plaza
Chicago, Ill. 60606

JOHN W. FARQUHAR
Director of Research & Tech. Serv.
American Frozen Food Institute
919 18th St. N. W.
Washington, D. C. 20006

GORDON N. FARRINGTON
Research Chemist
Garrott Res. & Developement
1855 Garrion Rd.
La Verne, Calif.

JAMES H. FISCHER
Secretary-Manager
Beet Sugar Development Foundation
P. O. Box 538
Ft. Collins, Colorado 80521

RICHARD G. FORD
Economist
Extension Service - U.S. Dept. of Agr.
Room 5531, S. Bldg.
Washington, D. C. 20250

THEODORE FRIEDLANDER
Owner, Friedlander & Associates
Marine Plaza
Milwaukee, Wisconsin 53202

WALTER GAY
Production Control Manager
Idaho Potato Starch Co.
P. O. Box 231
Blackfoot, Idaho 83221

DR. J. R. GEISMAN
Professor
Ohio State University
2001 Fyffe Ct.
Columbus, Ohio 43210

FELIX J. GERMINO
Asst, Manager
CPC International
Box 345
Argo, Ill. 60501

LOUIS C. GILDE
Director-Environmental Engineering
Campbell Soup Company
Campbell Place
Camden, New Jersey 08101

DR. ROBERT L. GOLDSMITH
Program Manager
Abcor, Inc.
341 Vassar St.
Cambridge, Mass. 02139

LEO R. GRAY
Agricultural Economist
U.S. Dept. of Agriculture
Economic Research Service
800 Buchanan Street
Albany, Calif. 94710

JOHN H. GREEN
Research Microbiologist
Nat. Center for FPC/NMFS/NOAA/USDC
Regents Drive, Univ. of Md. campus
College Park, Md. 20740

DR. STANLEY M. GREENFIELD
Asst. Administrator for Research & Monitoring
Environmental Protection Agency
Washington, D. C. 20242

ALEX GRINKEVICH
Project Engineer
Hunt-Wesson Foods, Inc.
1645 W. Valencia Drive
Fullerton, Calif. 92634

EDWARD H. GRODY
Manager - Mfg. Res/Develop.
Jewel Food Stores
1955 W. North Ave., Bldg. B
Melrose Park, Ill. 60160

G. J. GRONDIN
Technologist - Chemistry
Canadian Canners Limited Research Centre
Box 5032, 1101 Walkers Line
Burlington, Ontario, Canada

JACK H. HALE
Chemist
Robert S. Kerr Water Research Center, EPA
P. O. Box 1198
Ada, Oklahoma 74820

RALPH HANSEN
Ext. Agriculture Engineer
Colorado State Univ.
Fort Collins, Colorado 80521

DR. W. J. HARPER
Professor, Dept. of Technology
The Ohio State Univ.
2121 Fyffe Rd.
Columbus, Ohio 43210

HARRISON L. HATCH
Chief Engineer-Contadina Foods
Carnation Company
5045 Wilshire Blvd.
Los Angeles, Calif. 90036

DR. J. H. HETRICK
Prof. Dairy Technology
Univ. of Illinois
101 Dairy Mfg. Bldg.
Urbana, Ill. 61801

LEN S. HEUER
Food Technogogist
Kuner-Empson Company
P. O. Box 329
Brighton, Colorado 80601

ROBERT L. HILLER
Deputy Director - Office of Contracts & Grants for R & D
Environmental Protection Agency
1402 Elm St. - Third Floor
Dallas, Texas 75202

DR. JOHN M. HOGAN
Professor and Head
Food Science (Holmes Hall)
University of Maine
Orono, Maine 04473

HENRY T. HUDSON
Sanitary Engineer
Solid Waste Management Office, EPA
5555 Ridge Ave.
Cincinnati, Ohio 45213

E. L. JOHNSON
Vice President
Food Chemical & Research Laboratories
4900 9th N. W.
Seattle, Wash. 98107

FRANK R. JONES
Senior Chemical Engineer - Tech. Serv.
Pennwalt Corp.
11118 Manry Lane S. W.
Tacoma, Wash. 98498

DR. IVOR JONES
Assoc. Professor
Univ. of Washington
Div. of Marine Research
Seattle, Wash. 98105

EARL F. KARR
Customer Relations Manager
Peterson Mfg. Co., Inc.
2626 East 25th Street
Los Angeles, Calif. 90058

ALLEN M. KATSUYAMA
Assistant Head, Water and Waste Engineering Section
National Canners Association
1950 Sixth Street
Berkeley, Calif. 94710

H. GEORGE KEELER
Project Coordinator
Environmental Protection Agency
Washington, D. C. 20242

ROBERT S. KERN
Chief Engineer
National Fruit Product Co., Inc.
Box 609
Winchester, Virginia 22601

ROBERT L. KING
Sanitary Engineer
EPA - Water Quality Office
Room 415, Bldg. 22
Denver Federal Center
Denver, Colorado 80225

DR. MANFRED KROGER
Prof., College of Agric., Div. of Food Science & Industry
Pennsylvania State Univ.
105 Borland Laboratory
University Park, Penn. 16802

KENNETH D. KURTZ
Research Engineer
Hercules Inc., Environmental Services Division
900 Greenbank Road
Wilmington, Delaware 19808

LES LASH
Sales Engineer
Eimco - Envirotech
Box 300
Salt Lake City, Utah 84110

FRED C. LAUER JR.
Project Engineer
The R. T. French Company
Drawer AA
Shelley, Idaho 83274

PAUL F. LEAVITT
Asst. Chief Engineer
Gerber Products Co.
445 State St.
Fremont, Mich. 49412

DR. RAYMOND C. LOEHR
Prof. of Agric. and Civil Engineering
Cornell University
207 Riley Robb
Ithaca, New York 14850

ROBERT P. LOGAN
Principal Engineer
Bechtel Corp.
50 Beale St.
San Francisco, Calif.

EDISON LOWE
Head, Equipment Investigations
Western Regional Research Lab., ARS,USDA
800 Buchanan St.
Albany, California 94710

DAVID K. LUCAS
Market Manager, Bio-Systems Division
Autotrol Corporation
5855 North Glen Park Road
Milwaukee, Wisconsin 53209

DR. MAURICE A. LYNCH JR.
Manager, Montgomery Research Inc.
555 E. Walnut St.
Pasadena, Calif. 91101

BROMLEY MAYER
Director of Research
Knudsen Corp.
231 E. 23rd St.
Los Angeles, Calif. 90011

REGINALD E. MEADE
Research Associate
The Pillsbury Company - R & D
311 Second St. S. E.
Minneapolis, Minnesota 55414

WALTER A. MERCER
Director, Western Research Lab.
National Canners Association
1950 Sixth Street
Berkeley, Calif. 94710

FRANCIS A. MILLER
President, Key Equip. Co.
Div. Applied Magnetics Corp.
P. O. Box 6
Milton-Freewater, Oregon 97862

ED MITCHELL
Vice President Research
Calif. Canners & Growers
312 Stocton Ave.
San Jose, Calif. 95126

DR. JOHN E. MONTOURE
Associate Professor
Univ. of Idaho, Food Science Dept.
Moscow, Idaho 83843

DR. HOWARD MORRIS
Professor
Dept. Food Science & Industries
University of Minnesota
St. Paul, Minn. 55101

P. H. MULCAHY
Vice President
Envirotech Corp.
9501 Allen Drive
Cleveland, Ohio 44125

LEE A. MULKEY
Agricultural Engineer
Southeast Water Laboratory - EPA
Athens, Georgia 30601

JOHN E. MC CARTHY
Public Relations
Knudsen Corp.
231 E. 23rd St.
Los Angeles, Calif. 90011

GARY MC GRAY
Chemical Engineer
Sunkist Growers
310 N. Joy St., P. O. Box 640
Corona, Calif. 91720

DAVID B. NELSON
Sr. R & D Mkt. Repr.
Monsanto
5200 Sugar Maple Drive
Kettering, Ohio 45440

RICHARD W. NELSON
Chemical Engineer
National Marine Fisheries Service
2725 Montlake Blvd. E.
Seattle, Wash. 98102

PAUL R. NEUMANN
Plant Manager
A. E. Staley Mfg. Co.
Monte Vista, Colorado

JAMES H. OATES
Div. Environmental Control Manager
J. R. Simplot Co., Food Processing Div.
P. O. Box 1059
Galdwell, Idaho 83605

OTMAR O. OLSON
Regional R & D Repr.
Environmental Protection Agency
911 Walnut St., Room 702
Kansas City, Missouri 64128

RAYMOND ORR
IJC Coordinator
Dept. of Fisheries - Canada
227 Viewmount Drive
Ottawa 5, Ontario, Canada

DR. WILLIAM J. OSWALD
Prof. of Public Health & Sanitary Eng.
University of California, Berkeley
108 Earl Warren Hall
Berkeley, Calif. 94720

MICHAEL J. PALLANSCH
Research Chemist, Head, Dried Milk Products Investigations
Eastern Marketing & Nutrition Res. Div.
ARS, USDA
Washington, D.C. 20250

DR. C. D. PARKER
Chief Scientific Officer
Melbourne Water Science Institute Ltd.
15-21 Earl Street
Carlton, Victoria, 3053, Australia

DR. WAYNE L. PAULSON
Assoc. Prof., Environmental Engineering
University of Iowa
4110 Engineering Bldg.
Iowa City, Iowa 52240

GRANVILLE PERKINS
General Manager
Artichoke Industries, Inc.
11599 Walsh Street
Castroville, Calif. 95012

LESLIE E. PHILLIPS
Senior Process Engineer
Arthur G. McKee & Co.
10 S. Riverside Plaza
Chicago, Ill. 60606

EARL V. PORTER
Regional Air Pollution Control Director
U. S. EPA
9017 Federal Office Bldg.
Denver, Colorado 80202

E. B. PUGSLEY
Colorado Dept. of Health
4210 E. 11th Avenue
Denver, Colorado 80220

THOMAS P. QUIRK
Partner
Quirk, Lawler & Matusky Engrs.
505 5th Ave.
New York, N. Y. 10017

DR. JACK W. RALLS
Research Manager
National Canners Association
1950 Sixth Street
Berkeley, Calif. 94710

ALVIN H. RANDALL
President
National Canners Association
P. O. Box 3288, 4752 Liberty Rd. S. E.
Salem, Oregon 97302

EUGEN REMBOWSKI
Institute of Fermentation Ind.
Rakowiecka Street 36
Warsaw, Poland

GLENN A. RICHTER
Project Engineer
Cornell, Howland, Hayes &
Merryfield-Hill
1600 S. W. Western Blvd.
Corvallis, Oregon 97330

CHARLES RIS
Project Coordinator
Environmental Protection Agency
Washington, D. C. 20242

CHRIS D. ROBERTS
Plant Superintendant
Contadina Food Inc.
P. O. Box 29
Woodland, Calif. 95695

WALTER W. ROSE
Head, Water & Waste Engineering Sec.
National Canners Association
1950 Sixth Street
Berkeley, Calif. 94710

FARRELL RUPPERT
Manager-General Engineering
Beech-Nut, Inc.
460 Park Ave.
New York, N. Y.

PAUL RUSSELL
Partner, Harnish & Lookup Associates
615 Mason St.
Newark, N. Y. 14513

F. FRANK SAKO
Manager, FMC Corp., Environmental Engr. Lab.
P. O. Box 698
Santa Clara, Calif. 95052

THOMAS N. SARGENT
Sanitary Engineer
Southeast Water Lab - EPA
Athens, Georgia 30601

ROBERT E. SCHEIBLE
Manager of Environmental Control
Kraft Foods, Div. of Kraftco Corp.
500 Peshtigo Ct.
Chicago, Ill. 60690

CURTIS SCHMIDT
President, SCS Engineers
4014 Long Beach Blvd.
Long Beach, Calif. 90807

DR. H. G. SCHWARTZ JR.
Project Engineer
Sverdrup & Parcel
800 N. 12th
St. Louis, Missouri 63101

W. C. SENG
Chemical Engineer
Swift & Co., Research & Dev.
1919 Swift Drive
Oak Brook, Ill. 60521

ROY SHAW
Head, Red River Valley Potato
Processing Lab.
P. O. Box 113
E. Grand Forks, Minn. 56721

DR. S. DAVID SHEARER JR.
Chief, Natl. Source Inventory
Section
Air Pollution Control Of., EPA
411 W. Chapel Hill St.
Durham, N. C. 27701

K. LYNN SIRRINE
Research Chemist
The R. T. French Company
Drawer AA
Shelley, Idaho 83274

THOMAS F. SOLON
Programs Development
ITT Electrophysics
9140 Old Annapolis Road
Columbia, Maryland 21043

ROBERT M. SPALDING
Senior Engineer
Aerojet Medical & Biological
Systems
9200 East Flair Drive
El Monte, Calif. 91734

CLARENCE G. SPRAGUE
Civil Engineer
Green Giant Co.
Le Sueur, Minn. 56058

RONALD L. STABILE
Chemical Engineer
Agricultural Research Service,
USDA EMNRD
600 E. Mermaid Lane
Philadelphia, Pennsylvania 19118

DR. REGIS STANA
Senior Engineer
Westinghouse Research
Pittsburgh, Pennsylvania 15235

JOHN L. STEIN
Environmental Engineer
Anheuser-Busch, Inc.
722 Pestalozzi
St. Louis, Missouri 63118

RICHARD W. STERNBERG
Head, Water & Waste Engrg. Section
National Canners Association
1133 - 20th St., N.W.
Washington, D. C. 20036

CHARLES STEVENSON
Technical Manager
C-B Foods
P. O. Box 670
Rochester, New York 14602

HERBERT E. STONE
Manager, Technical Services
Del Monte Corp.
205 N. Wiget Lane
Walnut Creek, Calif. 94591

JOSEPH J. SU
Senior Engineer
General Foods Corporation
250 North St.
White Plains, N. Y.

WILLIAM F. TALBURT
Russell Research Center
P. O. Box 5677
Athens, Georgia 30601

DENNIS W. TAYLOR
Sanitary Engineer
Pacific Northwest Water Lab.
EPA
200 S. W. 35th St.
Corvallis, Oregon 97330

DONALD J. THIMSEN
Chief Environmental Control
Engineer
General Mills, Inc.
9000 Plymouth Ave. N.
Minneapolis, Minn. 55427

ERNEST G. TODD
Manager - Quality Control
Chef Reddy Foods Corporation
P. O. Box 607
Othello, Wash. 99344

RONALD A. TSUGITA
Senior Project Engineer
James M. Montgomery, Consulting
Engineers, Inc.
3717 Mt. Diablo Blvd., Suite 204
Lafayette, Calif. 94549

DONALD E. TYNAN
Research Liaison
Int. Min. & Chem. Corp.
Growth Sciences Center
Libertyville, Ill. 60048

DR. DAVID M. UPDEGRAFF
Head, Microbiology Sec.
Chem. Div.
Denver Research Inst.
University of Denver
Denver, Colorado 80210

IRA WARDER
Chemist
Gates Rubber R & D
1717 S. Acoma St.
Denver, Colorado

JOHN WELCH
Project Engineer
Sunkist Growers
P. O. Box 640
Corona, Calif. 91720

DR.LEO T. WENDLING
Professor, Extension Service
Kansas State University
Manhattan, Kansas 66502

MILES WILLARD
Magnuson Engineers, Inc.Consultant
Box 2774
Idaho Falls, Idaho 83401

JACK L WITHEROW
Chief, Agricultural Waste Section
Robert S. Kerr Water Research Center-EPA
P. O. Box 1198
Ada, Oklahoma 74820

GEORGE M. WONG-CHONG
Research Specialist
Monsanto Research Corp.
1515 Nicholas Road
Dayton, Ohio 45407

DR. N. H. WOODING, JR.
Professor, Div. of Food Science & Industry
Pennsylvania State University
105 Borland Laboratory
University Park, Pennsylvania 16802

★ U.S. GOVERNMENT PRINTING OFFICE: 1971-448-764/536